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Late Holocene environmental change at Aqualate Mere Staffordshire, UK

Ledger, P. M.

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Late Holocene Environmental Change at Aqualate Mere, Staffordshire, U.K.

P. M. Ledger

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Abstract

Palaeoecologial reconstruction of the last 3000 years was undertaken on a core from Aqualate Mere, Staffordshire, U.K. Diatom analysis was the main tool used for reconstruction and the data were analysed in conjunction with previously acquired pollen and environmental magnetics data. Core chronology is provided by ^{14}C and SCP measurements, also taken from previous work by Pittam (2006).

The findings of the investigation point to a mixture of direct climatic forcing, human mediated climatic forcing, and direct anthropogenic forcing on palaeoecology. Evidence for the impact of Bond Event 2 ca. 850 B.C., firstly mediated through human populations, and secondly, more directly on the mere, is suggested. Investigation of past eutrophic history of the mere suggests a strongly meso-eutrophic system through the time period represented by this core. An intensely eutrophic system is identified between ca. 400±145 B.C. and 50±105 A.D. This is attributed to natural conditions, perhaps exacerbated, but not directly linked to human activity. Evidence of high human impact appears through the Roman Period with indications of a major palaeoecological perturbation dated to between ca. 415±75 and 530±70 A.D. This is linked to deforestation and catchment erosion. Indications are that this episode led to a major shift in palaeoecology and the establishment of a clear, shallow, macrophyte dominated system.

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Finally I would like to acknowledge the support of my family through this sometimes taxing period. Dad, Mum, Mark and Katie thanks for your help and support!

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1.0 Project Context & Aims

1.0 Introduction

Lakes are increasingly recognised as excellent sensors of environmental changes, including climatic change, and multi-proxy studies of lakes are becoming increasingly common (Battarbee, 2000). Multi-proxy studies potentially offer the opportunity for the integrated responses of lake and catchment systems to climate and environmental change to be established (Battarbee, 2000; Birks & Birks, 2006). Diatoms, being ubiquitously expressed throughout aquatic environments, are one proxy that are effective in such studies; and recognised as excellent sensors of environmental change. This being due to their sensitivity to a number of ecological variables including pH, nutrients and lake levels (Dixit *et al*, 1992).

There have been a number of multi-proxy palaeoenvironmental studies undertaken in the U.K. to reconstruct environmental change, over a range of timescales. Examples include studies such as those at Goremire (Oldfield *et al.*, 2003) and Hawes Water (Bedford *et al*, 2004), both upland sites; a trend which has seen lowland regions somewhat neglected (Pittam, 2006). Further still, few have used diatoms. An exception to this trend would be at Diss Mere (Fritz, 1989), however this study is now over twenty years old. Diatom based palaeoenvironmental reconstructions have tended to focus on the past 200-300 years and the legacy of environmental degradation in this period, while establishing reference conditions for pre-industrial impacts. Such work has often aimed to reconstruct water chemistry via diatom based transfer functions, while neglecting the use of diatoms as broader ecological indicators (Bennion & Battarbee, 2007).

The English Midlands is an area that is particularly under-represented in such studies. No multi-proxy palaeoenvironmental studies have been undertaken in this region; however, there are a number of palaeoecological reconstructions in the area.

Palaeoecological studies have tended to focus on broad scale vegetational reconstructions such as those at Crose Mere (Beales, 1980) and Kings Pool (Bartley & Morgan, 1990). Few studies involving diatoms have been undertaken in this region. Exceptions include studies undertaken at Berrington Pool (Farr *et al*., 1991) and Whitemere (McGowan *et al*., 1999). This work however was not of a palaeoecological nature.

1.1 Aqualate Mere

A recent palaeoenvironmental study in the Midlands at Aqualate Mere was undertaken by Pittam (2006). This work provided the beginnings of a multi-proxy palaeoenvironmental study. Vegetation change was reconstructed and environmental magnetic measurements undertaken on a sediment core dated to ca. 2900 B.P. The focus of the study was twofold. One aspect analysed how accurately the palaeoenvironmental record of vegetation change reflects actual historical records. A second aspect used environmental magnetism to source sediment provenance using multi-parameter fingerprinting methods (Pittam *et al*., 2009)

Despite the focus of the study being on these aspects the work highlighted a feature of particular interest; extremely high concentrations of fossilised spores of the cyanobacteria *Anabaena* (Pittam, 2006). Such blooms are commonly cited as a diagnostic feature of highly eutrophic water bodies (Smol, 2002). High concentrations of *Anabaena* have previously been observed in Lake Gosciaz, Poland dating to ca. 1000 B.P., and were linked to cultural eutrophication of the lake (Ralska-Jasiewiczowa & van Geel, 1992; van Geel *et al.*, 1994). Pittam (2006) speculated that the rise in *Anabaena* at Aqualate also indicated eutrophication and was due to intensification of pastoral agriculture. However, the timing of this event at Aqualate Mere is likely in the Iron Age. An alternative explanation proposes that such blooms are natural phenomena, exacerbated by, but not dependent upon human activities (McGowan, 1999).

This work will focus on a diatom based study to reconstruct past palaeoecological changes at Aqualate Mere. Given the large catchment there is the opportunity to establish regional climate signals (Jacobsen & Bradshaw, 1981), which may be

recorded as changes to the diatom community of the Mere (Battarbee, 2000). Thus, this study will begin to address the research gap of diatom based studies of the late Holocene environmental history of the English Midlands. Additionally the work ties together that of Pittam (2006) to create a multiple proxy studies for the English Midlands. The relevance of undertaking further work is made more timely as the site is under threat from dredging. Natural England, as part of their Lakes Flagship Project, has selected the site as requiring restoration due to recent rapid sedimentation (Hutchinson, 2005). Should this proceed, a unique palaeoenvironmental archive stretching to the beginning of the Holocene would be destroyed (Pittam *et al*., 2009).

1.2 Project Aims

The overall aim of this study was to reconstruct diatom species assemblage changes to investigate the palaeoecology of Aqualate Mere utilising the sediment core of Pittam (2006). These changes were then set within the established chronology and interpreted with reference to the existing vegetation reconstructions and environmental magnetic measurements. The study aimed to investigate recent environmental change at Aqualate Mere by means of a number of specific objectives.

The specific objectives of the study were:

1. To investigate human impacts on the palaeoecology of Aqualate Mere and determine if they were the predominant forcing variable on the paleoecology of the lake.
2. To investigate the role of climate on the palaeoecology of Aqualate Mere. Furthermore, to establish if there was evidence for the diatom community reflecting established climatic cycles such as those identified by Bond *et al*. (1997; 2001) or events such as those summarised in Berglund (2003).
3. To investigate the trophic history of the lake and investigate the hypothesis that increases in *Anabaena* are the result of nutrient enrichment as a result of increasing anthropogenic impact (Pittam, 2006). Or were large blue-green algae blooms inferred by Pittam (2006) actually natural phenomena, common in the West Midland Meres (Reynolds, 1979; McGowan, 1999).

1.3 Thesis Structure

This thesis is divided into seven chapters. The following chapter will focus on establishing the broader context of this study through an in depth literature review. Chapter Three will establish the current state of knowledge about the study site. Chapter Four concentrates on a discussion of the methods used to achieve the research aims. Chapter Five is devoted to an analysis and discussion of the results of the diatom analysis and findings generated from the methods described in Chapter Four. Additionally the chapter draws upon and integrates the work of Pittam (2006) within the context of these findings. Furthermore it will seek to establish what the dominant forcing variables are behind changes recorded in the diatom stratigraphy. Chapter Six is the penultimate chapter and aims to provide a compelling narrative to explain the changes observed in light of the research objectives. This will proceed by means of discussing three key periods in the palaeoenvironmental record. Chapter Seven is the final chapter and will conclude by outlining the successes and failures and highlighting avenues for further study.

2.0 Literature Review

2.0 Introduction

This literature review will establish the theoretical framework for the research. The chapter will begin by establishing why lakes are used in palaeoenvironmental reconstructions. It will then progress to explain the mechanisms by which climatic and environmental information is recorded within them. A discussion of the ways in which sedimentary lake archives are unlocked and read, including the need to establish a secure chronology follows. This is followed by an assessment of the viability and uses of diatoms in paleoecology as sensors of environmental change. This assessment includes a review of the environmental information to which diatoms have proven to be sensitive to, along with highlighting their limitations. The chapter then concludes with a discussion of millennial and centennial scale climate cycles. The presentation of such events in the palaeo-record and an overview of key studies focusing on the past 3000 years follow. Reviews of the more specific studies that focus on environmental change in the English Midlands then conclude the chapter.

2.1 Lakes as Archives and Sensors of Environmental Change

Lakes are present throughout the landscape of the U.K. Present in many shapes and sizes they have formed from activities as mundane as local scale stone extraction or mining subsidence (Charlesworth & Foster, 1993), through to those sculpted by vast ice sheets such as Lake Windermere (Pennington, 1991). These lakes have one thing in common, they are archives of environmental changes (Cohen, 2003). The regular occurrence of lakes throughout the landscape makes them key terrestrial archives. This importance is more profound in lowland areas, such as the English Midlands, where other records, such as peat bogs are not present. The relatively high sedimentation rate of lakes (>1mm/yr) in comparison to peat bogs (≤1mm/yr) is

another key to their importance (Barber *et al*., 1994; Battarbee, 2000) allowing finer resolution studies.

2.1.1 Palaeolimnology

Palaeolimnology is the discipline of studying lakes for past environmental information and it is the discipline in which this study is firmly rooted. The field is diverse and encompasses a number of sub-disciplines. This research will specifically draw on the Quaternary geology strand of the science. This strand is interested in reconstructing palaeo climates and environments through the analysis of lake sediment cores (Cohen, 2003). Key to all palaeolimnological studies is recognition of the concept of Forcing Variables, Content Archives and Container Archives. This is a concept that has been discussed by other authors such as Birks & Birks (1980), but the terminology used here is of Cohen (2003). These are the broad names of the mechanisms which influence lakes and those which record and archive this information. Figure 2.0 is a graphical representation of how the variables interact and affect one another and Figure 2.1 is a simplified conceptual model.

A forcing variable is the mechanism by which something influences and regulates the history of a lake. These variables are usually external, but sometimes internal, to the lake body and include: climate, anthropogenic activity, geology, vegetation and aquatic biota (Cohen, 2003). It is these variables that we wish to reconstruct in a palaeolimnological study. For the purposes of this study the vegetational aspect has been previously reconstructed by the work of Pittam (2006). This study is predominately focused on resolving the contribution between climate and anthropogenic activity. In conjunction with their influence on local geology these variables are considered to be the key influences on a lake's history (Battarbee, 2000).

Container archives are the medium by which palaeoenvironmental information is recorded by a lake. There are three types of container archives and these are the geomorphology of a lake basin, the water chemistry and the accumulating sediments. This study is concerned with utilising the accumulating sediments, as such, the other container archives are simply recognised here.

The content archives are the physical, typically sedimentary, inputs into a lake's record. Examples of content archives are chemical, terrigenous and biological sediments and potential fossils intrinsic and extrinsic to the lake. In the case of this study it is the diatoms, in the form of fossils from the lake, that are the priority. Additionally, this work will review and draw upon information on extrinsic terrigenous sediments and pollen fossils reconstructed by Pittam (2006).

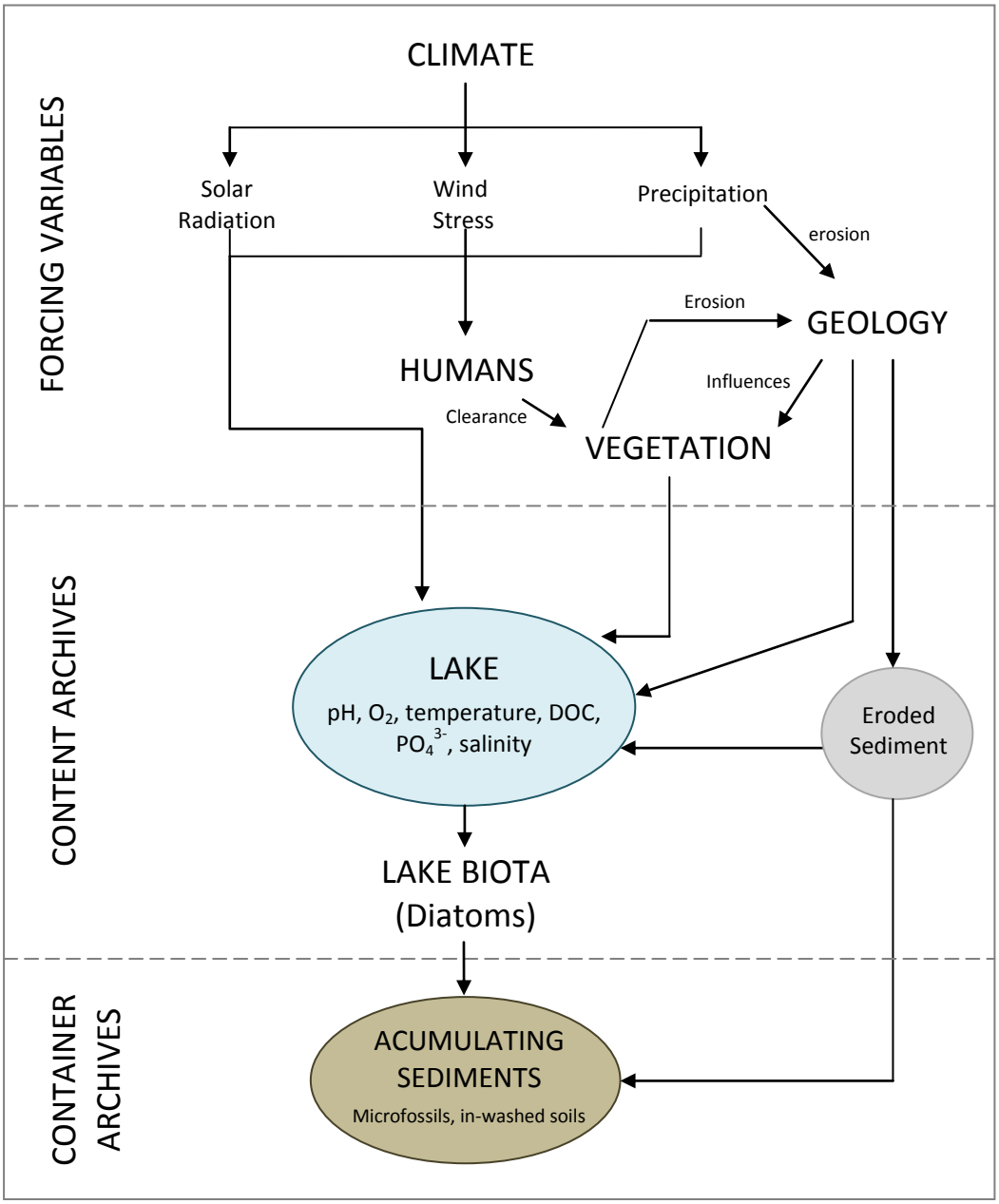

Figure 2.1 Various forcing variables and how they influence content and container archives with respect to this study.

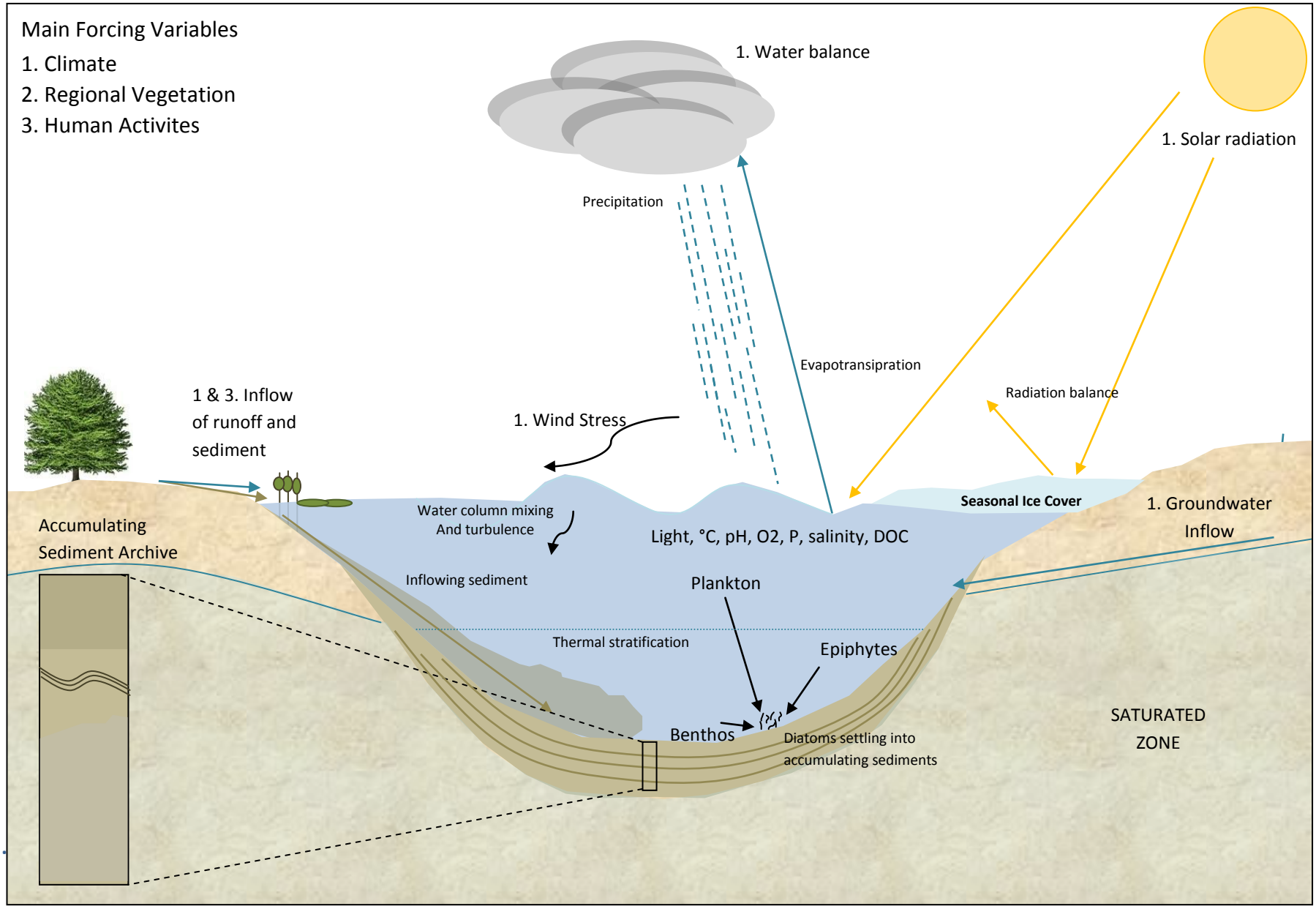

Figure 2.2 Simplified Conceptual Model of processes controlling and recording environmental change within lakes. (Adapted from Battarbee (2000) and Cohen (2003))

2.1.2 Climatic Sensors

The link between changes to lake ecosystems and climate is now well established. Climate is the pre-eminent forcing variable on lakes making them excellent sensors of climate and environmental change (Batterbee, 2000). Schindler *et al.* (1996) in north-west Ontario utilised modern day instrumental records to illustrate the links between climatic changes and consequent changes in lake biota and stratification. The link between changing climates and environments has also been demonstrated in sedimentary records from the high arctic (Douglas *et al.,* 1994), and in localities nearer to the study site, such as at Hawes Water (Bedford *et al.*, 2004).

The key processes with respect to records of climatic and environmental variability are those which affect radiation and water balance (Battarbee, 2000). Variation in these two key factors will influence *inter alia* the water column, sedimentation, seasonal ice cover, stratification and habitat availability. Changes in all or one of which can have a profound effect on the ecological balance in a lake (Fritz, 1996). Such changes would then be reflected in one or many of the content archives, which would contribute to the container archive of accumulating sediments. The nature in which lakes are affected by climate changes makes diatoms excellent sensors for such change (Dixit *et al*., 1992; Battarbee, 2000).

The type of lakes that will provide sedimentary records suitable for reconstructing environmental change are varied, both in origin, geography, age and chemistry; there being no pre-requisite for recording climate signals (Battarbee, 2000). Despite this, Fritz (1996) suggested that the most sensitive lakes would be those in extreme environments, or near climatic boundaries. Furthermore, large systems are likely to record extreme events, while smaller systems will be more sensitive to seasonal changes (Cohen, 2003). This suggests that Aqualate Mere, being a relatively large lake (in English terms) is likely to preserve records of extreme rather than seasonal events. However, Barber *et al*. (1999) suggested that lowland lakes may be unsuitable for recording climate signals due to the long history of anthropogenic disturbance in the lowlands.

2.1.3 Anthropogenic Influences

After climate the most significant influence on signals being recorded in the palaeolimnological record are humans. As such, palaeolimnological reconstructions from the late Holocene will always be confronted with trying to distinguish between anthropogenic and climatic signals (Barber *et al*., 1999; Battarbee, 2000).

Humans have been influencing and changing the landscape of the United Kingdom since the arrival of agriculture in the Neolithic, ca. 6000 years B.P (Roberts, 1998). There is, however, a debate surrounding the first signals of human impact in the palaeoecological record. An example being the debate surrounding whether the decline in the elm population *ca*. 5300 B.P. as evidenced at Crose Mere (Beales, 1980) is the first true marker of the impact of people, or in fact the result of Dutch Elm Disease (Twigger & Haslam, 1991).

Definitive evidence for significant anthropogenic impact does not appear until the first phases of widespread slash and burn tree clearance in the Bronze Age (Dark, 2000). In fact the earliest evidence for significant vegetational clearance in the vicinity of Aqualate Mere comes from Crose Mere. Beales (1980) timed widespread clearance and the rise of cereals to ca. 3900 cal. B.P. The timeframe of this study: ca. 3000 B.P. to present is, therefore, firmly entrenched in this period of human impact.

As signals of human impact are usually always indirect their presentation in the palaeoenvironmental record can be similar to climatic signals. This can make discerning between the human and climate signals troublesome (Roberts, 1998; Anderson, 2000). It is anticipated that this will present a challenge in discerning between climate and human signals in this investigation.

2.2 Unlocking & Reading Sedimentary Archives

It has been established in 2.11, that palaeolimnological information is recorded in three distinct archives. These are; lake water, basin geomorphology and accumulated

sediments (Cohen, 2003). This study is concerned with the latter and this section outlines how these archives are unlocked and read.

Sedimentary archives record palaeoenvironmental information indirectly through forcing variables, Figures 2.0 and 2.1. Variations in these inputs directly affect biological, hydrological and chemical processes occurring in a lake, which become expressed in accumulating sediments (Fritz, 1996; Battarbee, 2000). The manner in which these processes are affected will be expressed differently within the archive. The key to a palaeolimnological study is how to read the messages in these sedimentary archives. However, before this can proceed we must be able to access them.

A large variety of tools are available for extracting sedimentary archives, all of which involve extracting sediment cores from the lake bed (Oldfield & Richardson 1990). A variety of corers have been developed, which are suitable for a specific type of site and are capable of collecting different lengths of material. Besides choosing a type of corer another key point to consider in unlocking a sedimentary archive is the selection of a coring location. Jacobsen & Bradshaw (1981) suggest that the placement will determine whether the core reflects regional or local signals. For local signals coring should be nearer to the shore while regional signals will best be reflected from a core close to the centre of a lake (Battarbee, 2000).

2.2.1 Establishing a Chronology

Before any information can be gleaned from a sediment core it is essential to establish a chronology. With a sound chronology established it is possible to anchor events in time and calculate sediment fluxes and process rates (Cohen, 2003). A chronology is also important when attempting to correlate events across from one site to another and link events within a core to known historical events.

A large number of potential methods are available to a palaeo-researcher (Walker, 2005). This section, however, will only review radiocarbon (^{14}C) dating and Spheroidal

Carbonaceous Particles (S.C.Ps.); the methods used by Pittam (2006) to derive the chronology relevant to this work.

2.2.2 Radiocarbon (^{14}C) Dating

Radiocarbon, or carbon 14, dating is the most well established method for dating the past (Lowe & Walker, 1997; Bell & Walker, 2005; Walker, 2005). It has been widely applied across a number of disciplines including the palaeoenvironmental and archaeological fields. However the method is limited in its application beyond ca 45,000 years and is of little use dating deposits of the post-industrial period. Despite these limitations it is the pre-eminent method for dating the Holocene (Walker, 2005).

Basic Principles

The basic principles are thus: carbon exists in three isotopic forms; ^{12}C, ^{13}C and ^{14}C whereby ^{14}C is radioactive, and decaying at a constant rate. This decay occurs, through the emission of beta β particles, until the ^{14}C becomes a stable form of nitrogen, ^{14}N. Of these three isotopes ^{12}C and ^{13}C are both naturally occurring, whereas ^{14}C is produced by the interaction of cosmic ray neutrons and elemental Nitrogen in the upper atmosphere. This interaction leads to proton loss and neutron capture by the Nitrogen giving birth to ^{14}C. This then interacts with Oxygen forming radioactive carbon dioxide ($^{14}CO_2$). From this point it mixes with the other isotopic forms entering the global carbon cycle via photosynthesis. From this point the ^{14}C makes its way into higher organisms through the food chain. At this stage the ^{14}C within the organisms is already decaying, but it is being replenished from the atmosphere so there is no net loss of ^{14}C. Once the organism dies the ^{14}C is no longer being replenished and the ^{14}C begins to decay. This decay occurs at a constant rate with the half-life for an atom of ^{14}C being. 5,730 years. It is by the use of Accelerator Mass Spectrometry (AMS) to measure the quantity of ^{14}C present in a sample relative to its decay products, that an age is derived (Lowe & Walker, 1997; Walker, 2005).

Calibration

In the 1940s, when radiocarbon dating was being developed, Libby made the assumption that the atmospheric concentrations of ^{14}C have not varied significantly over time (Walker, 2005). This key assumption allowed radiocarbon ages to be directly translated into calendar dates, but has since proven to be unsustainable. Researchers working on tree-ring chronologies noticed discrepancies between radiocarbon ages for wood and those produced by dendrochronological dating. This lead to large errors between calendar and radiocarbon ages. The variation was attributed to long term variations in the production of ^{14}C in the atmosphere and a number of causal mechanisms proposed. The first involves modulation of cosmic rays by either variations in the earths's geomagnetic field (Stuiver *et al*., 1991), cited in Walker (2005) or solar wind intensity (van Geel *et al*., 2003b). The second revolves around changes to oceanic circulation, which would alter the rate at which CO_2 is released and absorbed by the oceans (Goslar *et al*., 1995). Despite a lack of understanding of the mechanism behind variations in ^{14}C, methods of calibrating radiocarbon ages with calendar ages have been developed (Walker, 2005). Calibration curves have been developed mainly using dendrochronological records. The most recent of these, INTCAL04, takes the calibration curve back as far as 10,279 calendar years B.P. (Reimer *et al*., 2004).

Sources of Error

Aside from the aforementioned errors, a number of other sources of error in radiocarbon dating are well documented (Lowe & Walker, 1997; Walker, 2005; Bell & Walker, 2005). Two sources of error are of particular concern in lake sediments, the first of which is contamination. Contamination of a sample can result in major errors in radiocarbon dates: Walker (2005) states 1% 'old' carbon contaminating a modern sample can increase a date by approximately 80 years. This effect becomes more pronounced in older samples with 1% reducing a 17,000 year old sample by 600 years. One such mechanism postulated for this effect in lake sediments is root penetration, or bio-turbation by benthic organisms, taking 'newer' carbon to older sediments at depth.

A second source, exclusive to lake sediments is mineral carbon error, whereby older, more depleted, ^{14}C from the catchment is washed into the lake. This carbon then artificially ages samples in the lake. The problem is predominant in lakes with high allochthonous sedimentation such as the Kings Pool, Stafford (Bartley & Morgan 1990).

2.2.3 Spheroidal Carbonaceous Particles

SCPs are a relative newcomer to the suite of palaeoenvironmental dating techniques, with the first profile established by Griffen & Goldberg (1981). The particles are the by-products of high temperature, but incomplete, combustion of fossil fuels associated with the industrial revolution (Rose *et al.*, 1995). This close relationship between the particles and a well documented historical period makes them an excellent time-specific stratigraphic marker (Rose *et al*., 1995). SCPs became ubiquitous in the environment via power station chimneys, leading to widespread dispersal. The particles were carried from their source by winds and deposited through the environment. In some cases the particles would be deposited into lakes.

The concentration of SCPs in the atmosphere, and hence the concentration available to settle into lakes has waxed and waned since their first appearance. Work by Rose *et al.* (1995) reconstructed SCP profiles for a number of sites throughout the U.K. This work attempted to date the first appearance of SCPs and changes in their concentrations using a ^{210}Pb chronology. The first appearance of SCPs in the palaeoenvironmental record was variously dated, with the earliest date falling in the 1830s. Since this work the SCP method of dating sediments in the U.K. is now widely used such as by Barber *et al*. (1999), Shotbolt *et al.* (2001) and Rosen & Dumayne-Peaty (2001).

2.2.4 Reading Archives: Diatoms

With material collected and a chronology established it becomes time to read this information. This requires the study of a proxy, which is used as an indicator for some aspect of environmental change (Cohen, 2003). A large variety of proxies for studying environmental and climate change are available. This work is focused on studying

what microfossils, specifically diatoms, can infer about past environmental and climatic change. Diatoms are unicellar microscopic algae which are abundant in almost all aquatic habitats (Stoermer & Smol, 1999). This, coupled with their high degree of sensitivity to a wide range of ecological variables makes them excellent indicators of environmental change (Dixit *et al.*, 1992).

Studies of Diatoms have a long history, beginning almost 200 years ago. The emphasis of early work tended to focus on classifying and creating taxonomical schemes for diatoms (Stoermer & Smol, 1999). By the twentieth century researchers were seeking to assign ecological ranges to different genera and species (Bradbury, 1975). 1937-1939 saw the first publication of such a scheme: for pH by Hustedt. With the development of such schemes it became possible to begin to use diatoms to reconstruct and infer palaeoenvironments (see Pennington, 1943; Battarbee, 1978; Farr *et al*., 1991; Battarbee, 2000; Anderson, 2000; Selby & Brown, 2007). A large body of research now exists on using diatoms to reconstruct past changes, *inter alia* lake levels, pH, nutrient loading and salinity (Stoermer & Smol, 1999). This has been achieved both qualitatively, through the use of coded checklists and descriptive reconstructions (Fritz, 1989; Selby & Brown, 2007) and, more recently, quantitatively, via transfer functions (Battarbee, 1984).

2.2.5 Taxonomy

The study of diatom taxonomy dominated the early part of the twentieth century. This period saw prolific researchers such as Ehrenberg, Grunow, Cleve, Hustedt and Cholnoky name and classify hundreds of species (Barber & Haworth, 1981; Round *et al*., 1990; Stoermer & Smol, 1999). Despite their efforts, the invention of the electron microscope, in the mid part of the century, saw the need to reassess the many such classification schemes. This lead to a whole host of reinterpreted and newly discovered species, and many taxonomical debates still rage today (Round *et al*., 1990).

With new ideas surrounding taxonomy and classification a number of researchers began to publish new works identifying diatoms. These built on earlier illustrated

works produced by authors such as Schmidt, van Heurck and Cleve-Euler (cited in Barber & Haworth, 1981). Foged (1974; 1977) published accounts of the diatoms of Iceland and Ireland while in German, Krammer and Lange-Bertalot (1986; 1988; 1991) produced comprehensive accounts of the diatoms identified in Central Europe. Complimentary to such books was an English text by Barber and Haworth (1981) which was a guide to assist in the taxonomical classification of species and genera. An even more recent tool has been published by Hartley *et al*., (1996), which provides an illustrated account of diatom species identified in British waters.

2.2.6 Environmental Reconstruction

Two main methods for using diatoms to infer environmental and ecological information have been developed: the transfer function approach, and the so called Systems and Spectra (Stoermer & Smol, 1999). The differences between the two approaches are manifest and summarised below.

Transfer functions

Transfer functions are quantitative reconstructions and seek to use diatoms to reconstruct numeric values for the variables being reconstructed (Hall & Smol, 1999). Hence, they are powerful tools for reconstructing palaeoenvironments (Dixit *et al.*, 1992; Bennion & Battarbee, 2007). In order to carry out such work, first, a large dataset of modern diatoms from a variety of lakes must be collected (Dixit *et al.*, 1992). Lake water samples must then be analysed for the variable of interest and the information collated to calibrate the transfer function (Hall & Smol, 1999). The fossil diatom assemblage can then be fed into the transfer function to generate a reconstruction of the variable of interest.

Despite the strengths of transfer functions there are also weaknesses. One of the key weaknesses of transfer functions in relation to this study is that they are labour and time intensive. The second is that they are predominately focused on reconstructing chemical water quality variables (see Battarbee, *et al.*, 1984; Battarbee *et al.*, 1999; Hall & Smol., 1999). This emphasis on water quality variables often leads to a lack of

recognition of the broader ecological conditions of a water body (Bennion & Batterbee, 2007; Birks & Birks, 2006). Bennion & Battarbee, (2007) recently argued that a broader recognition of the palaeolimnological record and ecology may be beneficial, as it allows the structural and functional aspects of an ecosystem to be observed. A third potential weakness of transfer functions is that they have been found to be relatively insensitive. In particular their ability to accurately reconstruct total phosphorous has been questioned (Birks & Birks, 2006).

Systems and Spectra

This study will focus on the qualitative approach to palaeoecological reconstruction through the use of so called Systems and Spectra. This approach is the older of the two methods and will be used to attempt to reconstruct the nutrient loading, palaeo lake levels, pH and salinity. Studies employing this approach include: reconstructing nutrient loading and pH (Selby & Brown, 2007; Gaillard, 1991) and salinity (Van Dam, 1994).

The systems and spectra method has developed from early work by authors such as: Hustedt (1937-1939; 1953) and Cholnoky (1968). These authors, *inter alia*, related the presence of diatom taxa to specific ecological controls such as pH and nutrient availability (Battarbee, 1986; Van Dam *et al*., 1994). The majority of this work was progressed in a somewhat haphazard manner and there was little standardisation between the authors (Van Dam, 1994).

The first attempts to draw together all of the ecological and taxonomical information were made by Lowe (1974) and Beaver (1981). This work however was centred on the diatoms of the Americas, particularly the United States and Canada. Consequently this work omitted a number of common western European forms. Denys (1991), synthesising the work of earlier authors produced a check-list of diatoms and compiled the first European list. Based on diatoms from Belgium, he applied scores to fifteen different ecological characteristics, including *inter alia* pH, trophic status and habitat. A second European list was produced by Van Dam (1994). This work was based on freshwater forms found in the Netherlands and was similar to Denys (1991), however,

only seven ecological characteristics were covered. This work will primarily focus on the use of the lists by Denys (1991) and Van Dam (1994), and will draw on other sources when relevant information is not presented therein.

2.2.7 Lake Level Reconstruction

Alongside being excellent sensors of ecological changes, diatoms also make useful tools for reconstructing palaeo lake levels (Wolin & Duthie, 1999). A number of methods of using freshwater diatoms to reconstruct palaeo lake levels have been advanced. The most common is to use the ratio of planktonic to periphytic species (Jones & Jordan, 2007). Other methods are often used in conjunction with such ratios, which revolve around diatom responses to physical and chemical changes (Wolin & Duthie, 1999). Such signals include pH, nutrient loading and turbulence.

Using species ratio changes is by far the simplest of the methods outlined above and have been widely used in studies by Gasse *et al*., (1989) and Selby & Brown (2007). Such studies work on the assumption that as water levels fluctuate, changes occur in the habitats available. Falls in lake levels lead to an increased area of the lake bottom lying within the photic zone and *vice versa*. This in turn leads to an increase in periphytic species, hence a shift in the planktonic to periphytic ratio (Wolin & Duthie, 1999).

Of the other methods mentioned nutrient loading is the most troublesome. Decreasing lake levels may lead to concentration of nutrients present within a lake. However, this signal could easily be the result of anthropogenic disturbance and caution must be exercised using this method (Wolin & Duthie, 1999). It has also been noted from work in southern Sweden that the changes induced on diatom flora by lake level fluctuations, may manifest in a similar way to trophic changes (Gaillard *et al*., 1991). Using pH signals can follow a similar logic to those of nutrient changes. Decreasing pH is taken to reflect falling lake levels as less water flows into the system and H^+ concentration increases relative to base cations. The converse of this has also been demonstrated by Bradbury (1986), (cited in Wolin & Duthie, 1999), where

increasing pH was taken to reflect inflow of low conductivity water from winter snow melt. Again this signal can be misleading and is used cautiously.

A more useful method for reconstructing lake levels is to examine diatom species associated with turbulence (Wolin & Duthie, 1999). The genus *Aulacoseira* has been shown to be one such indicator as it is a heavily silicified diatom requiring turbulence to maintain itself in the water column (Bradbury, 1975). Studies by Owen & Crossley (1992) and Pilskaln & Johnson (1991) have interpreted increases in *Aulacoseira* as increased windiness across shallow lakes.

2.2.8 Diatoms and Climate

The use of diatoms to infer past climates is an ongoing area of research and there is much debate as to their suitability (Anderson, 2000). Reconstructions of diatom sequences from throughout the Holocene have shown great variability over periods of climate change (Birks, 1986). However, it is unclear whether such changes reflect climate or water quality changes caused by other forcing variables, themselves being mediated by climate (Anderson, 2000).

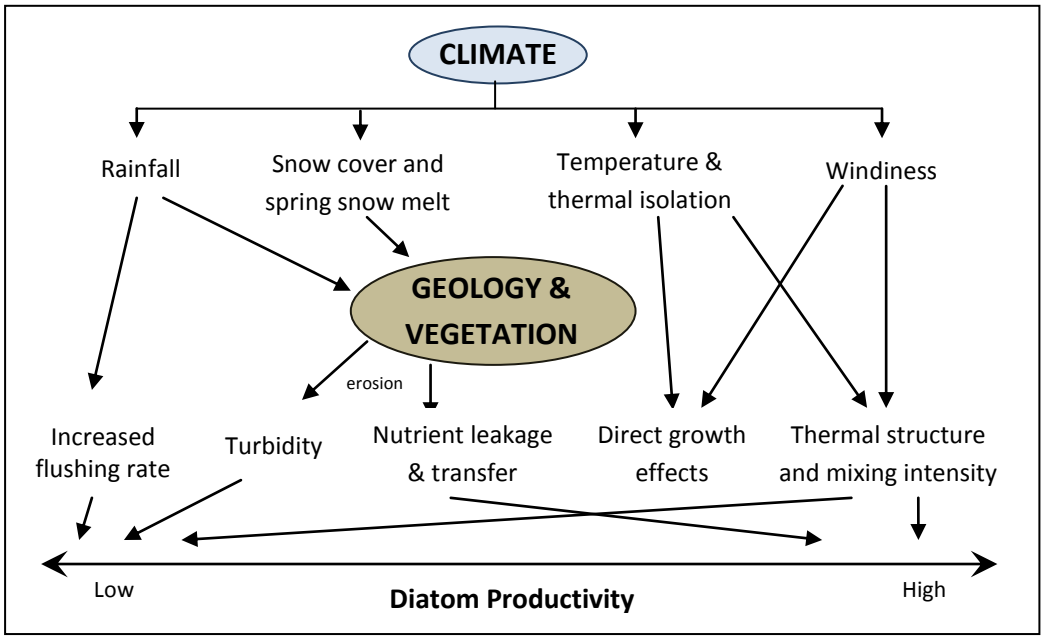

Figure 2.3 The Ways in which climate influences diatoms abundance in lakes (adapted from Anderson, 2000).

A number of studies have been undertaken to attempt to directly link diatoms to climate through temperature transfer functions. The majority of this work has noted that although diatoms do appear to respond to temperature they are not dependent upon it. Hence, diatoms are inappropriate for reconstructing lake or air temperatures (Anderson, 2000). This assertion is supported by the fact that diatom communities tend to be rather cosmopolitan. Genera such as *Fragilaria* have been identified across a wide range of environmental contexts; including late glacial (Pennington, 1991), the high arctic (Douglas *et al*., 1994) and in warmer climes (Fritz, 1989). Given this wide distribution Anderson (2000) argues other factors must be more important in controlling distribution. As is demonstrated in Figure 2.2 diatoms are controlled by factors other than temperature. They do, however, respond to climatic shifts indirectly by means of climate influence on variables such as pH, nutrient loading and turbulence (Anderson, 2000).

2.3 Climate and Vegetational Change

Climate is not a static concept; it is forever changing and evolving. The Intergovernmental Panel on Climate Change (IPCC) defines it as the 'average weather' or 'the statistical description, in terms of the mean, and variability of relevant quantities over a set period of time (Solomon *et al*, 2007). Although we know that climate is dynamic, the mechanisms behind it are less well understood.

The past two sections have dealt with the mechanisms of how records of environments and climate are recorded in lakes, and how they are read. This section will now briefly discuss some of the known mechanisms forcing climate that operate at timescales relevant to this study. A discussion of the evidence for such events in the palaeo-record then follows. The section then concludes by setting the context, through a discussion of the evidence for late Holocene environmental change in the English Midlands.

2.3.1 Climate Cycles & Associated Events

The recognition of cycles and events that drive long term, millennial scale, climate variability is a relatively recent shift in understanding of Holocene climate change (Turney, 2008). Previously, the most widely acknowledged climatic cycles were those described by Milankovitch orbital theory governing glacials and interglacials (Lowe & Walker, 1997; Bell & Walker, 2005). Within the glacial periods a series of cold, stadials, and warm, interstadials, were recognised, but the cyclicity of such events was hotly debated.

The 1990s saw an evolution in the understanding of the forces driving long term climate variability. Working on cores from Greenland, Dansgaard *et al*. (1993) had recognised a series of recurrent warm interstadials. However, it took Bond *et al*. (1993) to recognise that these Dansgaard-Osechger Events were in fact warming events of declining amplitude. Furthermore, they identified that the events were part of a cooling cycle, of a return frequency of *ca*. 10-15ka, that ended with a massive release of ice into the North Atlantic, known as a Heinrich Event. Having recognised these glacial cycles Bond *et al*. (1997) went further. They recognised what they speculated were the continuation of Dansgaard-Osechger Events into the Holocene, at a return frequency of approximately 1,470 years. Eight of these so-called Bond Events have been recognised through the Holocene; however, the climatic signal of these events is not always clear. Some correspond to episodes of desertification, others to cooling (Bond *et al*., 1997; 2001). Further climate cycles, recurring at even shorter frequencies have also been postulated. These include *ca*. 550 and 1000 year cycles identified in North Atlantic sediment cores (Chapman & Shackelton, 2000), and *ca*. 600 to 1100 year cycles from mire surface wetness records (Hughes *et al*., 2000; Langdon *et al*., 2003).

Bond Events are of particular interest to this study as they are linked to significant alterations in global distribution of heat in the oceans via the thermohaline circulation (Bond & Lotti, 1995; Lowe & Walker, 1997). Such alterations to the strength of ocean circulation affect broad changes in weather patterns (Lowe & Walker, 1997) and the effects on climate have been widely discussed (Berglund, 2003; Plunkett & Swindles,

2008; Wanner *et al*., 2008). Given that Aqualate Mere is a lowland catchment its ecology and environment will be less susceptible to disturbance from minor climatic shifts. As a result more extreme, millennial scale, perturbations in climate such as Bond Events are likely to be recorded (Fritz, 1996; Barber *et a*l., 1999) over more minor fluctuations.

2.3.2 Late Holocene Environmental Change (ca. 3500 B.P. to present)

Climate, therefore, is dynamic and is imbued with cyclical events. The following pages are now devoted to a discussion of the evidence for climatic variation from *ca*. 3500 B.P. to the late Middle Ages, *ca*. 300 B.P. The evidence presented will focus on Europe in general, but wherever possible U.K. based studies will be discussed. Furthermore the affects of such changes on human societies are also considered.

The Bronze Age

To begin we will set the scene just prior to the time slice relevant to our investigation; the middle to late Bronze Age. All of the indications from this period are of a favourable climate. Human societies had spread far and wide and were occupying areas now considered marginal or uninhabitable. Evidence from the south-west of England and the Pennines showed occupation and cultivation of the landscape to respective elevations of 450m and 600m (Lamb, 1995). Gearey *et al*. (2000) provide radiocarbon dated phases of woodland clearance from Bodmin Moor, which identify a 'high tide' of human activity during the Bronze Age. At the coasts trees were growing in areas that today are considered too windy. Even more unusual are the numbers of megalithic monuments, which track the solstices, being constructed in areas that are now among the cloudiest parts of the U.K. (Lamb, 1995).

The Late Bronze to Iron Age

Following this favourable period, climate began to deteriorate, attested by bog growth ca. 3500 – 2800 cal. B.P. and increasing Alpine lake levels (Lamb, 1995). This period towards the end of the Bronze Age and beginning of the Iron Age was complex. Cold

wet conditions began ca. 3300 cal. B.P., which led to flooding of lowland lake settlements, and prevailed until ca. 3000 cal. B.P. (Berglund, 2003). Following this deterioration climate ameliorated slightly around 3000 cal. B.P. Settlement of European lake areas began once more and peat began drying in European sequences (Lamb, 1995).

This climatic amelioration did not last long and by *ca*. 2800 cal. B.P. there is evidence of a major climatic downturn, which has been associated with Bond Event 2 (Lamb, 1995; Van Geel *et al*., 1996; Bond *et al*., 1997; Berglund, 2003; Plunkett & Swindles, 2008). Lamb (1995) notes glacial growth in Norway from 2750 cal. B.P., and at Tregaron in Western Wales, extensive peat bog growth of 1m in just 400 years between 2800 and 2400 cal. B.P. This is supported by evidence for general glacier expansion across the northern hemisphere from 3000 cal. B.P. to 2300 cal. B.P. summarised by Wanner *et al*. (2008). Further evidence comes from terrestrial archives such as in the Netherlands. Here, van Geel *et al*. (1996) dated increasing peat bog wetness, and migrations from marginal settlement areas to 2800 to 2650 cal. B.P. A similar study from a raised bog in North-western Ireland dated an abrupt shift to wetter conditions to 2700 cal. B.P. Swindles *et al*., (2007). Increased wetness has also been identified around this time in Scandinavia at Lake Bjäresjösjön where a general lake level rise is indicated ca. 2600 cal. B.P. (Gaillard *et al*., 1991).

The presentation of this period in the palaeoecological record however is indistinct. Dark (2006) summarised a series of 75 palaeoecological reconstructions from across the U.K and found no evidence for widespread abandonment of land. Evidence for the deterioration was found in some sequences. Increased clearance in some upland locations was interpreted as people increasing land for cultivation to guard against the risk of crop failure. In lowland central and southern England there was consistent evidence for regeneration such as at Crose Mere (Beales, 1980). Dark (2006) interpreted this as possible movement from sites that were becoming water logged due to increasing rainfall.

The Roman Period

The deterioration in climate persisted until around 2250 cal B.P. and was followed by a gradual climatic recovery. This recovery coincided with the emergence, and is viewed to have mirrored the expansion, of the Roman Empire over the following centuries through to *ca*. 1450 – 1400 cal B.P. (Lamb, 1995). Anecdotal evidence from this time mentions vines growing and wine being produced as far north as central England. Further evidence is the low frequency of recorded sea floods through this period and a high stand in relative sea level at around 1550 – 1450 cal B.P. (Lamb, 1995).

Reconstructions of tree rings through this period also indicate warmer temperatures (Briffa, 2000; Eronen *et al*., 1999). Alongside the evidence from tree rings palynological evidence from the Roman period would appear to indicate a change to a more stable climatic regime. Vegetational reconstructions undertaken across the U.K. indicate an expansion of cereal cultivation in the period and increasing clearance of woodland possibly for arable cultivation (Beales, 1980; Fritz, 1989; Fyfe *et al*., 2004)

Post Roman Migration Period

Around 1400 cal B.P. another climatic shift towards deteriorating climate began, associated with Bond Event 1 (Bond *et al*., 1997; Berglund, 2003). The beginning of this deterioration is noted to have coincided with and linked to the collapse of the Roman Empire (Lamb, 1995). The withdrawal of Roman garrisons has been linked with landscape abandonment across a great deal of Northern England in this period (Dumayne-Peaty, 1998; 1999). However the evidence for such abandonment is less distinct across the rest of the country.

This climatic downturn is described by Lamb (1984) as a period of trending to a cooler wetter climate ca 1400 – 1150 cal. B.P. Two mires in the north-west of England: Walton and Bolton Fell Moss, indicating a shift to wetter regimes *ca*. 1400 – 1600 cal. B.P. support this assertion (Hughes *et al*., 2000; Barber, 1982). Evidence from Northern Ireland supports increased wetness around this time, with a particularly severe phase ca. 1225 – 1100 cal. B.P. (Barber *et al*., 1999). In Finland this period was

punctuated by a sharp decline in tree ring growth around 1400 cal B.P., followed by a brief recovery and a sharp decrease again to 1100 - 1150 cal. B.P. (Eronen *et al*., 1999). Further evidence from Scandinavia indicates a shift to wetter climes where rising water levels have been inferred at Lake Bjäresjösjön (Gaillard *et al*., 1991).

The Mediaeval Warm Period

Following the climatic downturn of the previous centuries, the centuries from ca. 1050 B.P to 650 B.P. saw a trend to warmer more stable weather. This was centred on 950 - 750 cal B.P., and dubbed the Mediaeval Warm Period (Lamb, 1984; 1995). This period was also that of the Norse Viking expansions into Iceland and Greenland, believed to be a result of a more favourable climate (Fitzhugh and Ward, 2000). References to cultivation of land in Dartmoor and Northumberland to respective elevations of 400m and 320m appear to support this assertion. Other anecdotal evidence from ca. 1280 A.D. suggests that cultivation of hillsides in the English Pennines had reached such a height that there was no space for grazing sheep (Lamb, 1995).

Again evidence from tree rings supports the anecdotal observations of a more settled climate. Briffa (2000) presents evidence for prolonged increasing tree ring growth at northern latitudes between 1000 cal. B.P. and 750 cal. B.P. Whereas Eronen *et al*., (1999) place a period of increased tree ring growth and hence warmer temperatures between 1100 and 900 cal. B.P. Further evidence for a warm stable period around this time comprises reduced lake catchment erosion, and high tree lines and glacial retreat in Scandinavia (cited in Berglund, 2003).

The Little Ice Age

The Little Ice Age was a term coined to describe a period of prevailing cold climate following the mediaeval warmth. Using a number of anecdotal records Lamb (1995) timed the beginning of this decline to ca. 650 cal. B.P. citing increased storminess and a run of very wet summers between 1313 and 1317. The timing of this deterioration was found to be earlier in collation of historical documentary sources. Britton (1937)

showed that a phase of severe and wet winters began ca. 800 B.P. peaked, ca. 700 cal. B.P. and continued on until 500 cal. B.P.

This period was not uniformly cold or wet and appeared to go through slight ameliorations before once again deteriorating. Evidence for this general progression towards wetter weather and phasing can be found in records from numerous peat bogs and mires. Barber (1982) working at Bolton Fell Moss timed wet shifts during the period to *ca*. 1300 – 1400, followed by a recovery and deterioration again ca. 1600. Working on the nearby site at Walton Moss Hughes *et al*., (2000) identified a general transition to wetter weather from *ca*. 900 cal. B.P. Other work on bogs from Northern Ireland and the Cairngorms identify wet shifts at around 1685 and 1715 (Barber *et al*., 1999).

Alongside evidence for increased wetness Jones *et al*., (1998) presented reconstructions from tree rings. These indicated that the coldest year of the last millennium fell in 1601 and the coldest decade was 1691-1700. Further evidence for cold and wet weather through this period is available from Scandinavia. This shows evidence for glacier advance, increasing catchment erosion and increasing lake levels (cited in Berglund, 2003). Alongside this evidence for catchment erosion around this period is a study from Slapton Ley, Devon. Foster *et al*. (2000) identified an increase in sedimentary deposition in the Ley around this period. They speculated that deteriorating climate could have been the causal factor in the erosion of agricultural soils around this period.

Summary

As has been demonstrated above and is summarised in Table 2.2, the climate and environment of the past three millennia has swung between periods of calm and periods of cool. The effects of such changes on vegetation and indirectly on human populations and society have been widely documented (Berglund, 2003). However, the effects of such changes on lake ecology and the response of Lake Biota to such changes are less so. This gap in knowledge of the effects of climatic and

environmental change is particularly acute in the English Midlands, which the following section highlights.

Dates Period	Climatic Event(s)
Bronze Age (ca. 3500 – 3300 B.P.)	'High tide' of landscape cultivation up to 450-600m (Lamb, 1995; Gearey, 2000). Megalithic (solstice tracking) monuments constructed in what are presently some of the cloudiest parts of the U.K. (Lamb, 1995).
Bronze - Iron Age (ca. 3300 – 3000 B.P.)	Climatic deterioration attested by bog growth, rising lake levels and flooding of lowland settlements (Lamb, 1995; Berglund, 2003)
Iron Age (ca. 3000 - 2800 B.P)	Slight climatic amelioration with resettlement of lowland lake sites (Lamb, 1995).
Iron Age (ca. 2800 - 2300 B.P.)	Climatic deterioration characterised by bog growth, glacier growth, rising lake levels and abandonment of marginal settlements (Gaillard *et al*., 1991; Lamb, 1995; van Geel *et al*., 1996; Berglund, 2003; Swindles *et al*., 2007; Wanner *et al*., 2008).
Roman Period (ca. 2250 – 1450 B.P)	Climatic recovery and stability. Evidence cited includes low frequency of sea floods through the period and high stand in relative sea level (Lamb, 1995). Tree ring evidence indicates warming temperatures (Eronen *et al*., 1999; Briffa, 2000). Palynological evidence for widespread increase in agriculture (Beales, 1980; Fyfe *et al*., 2004).
Migration Period (ca. 1400 – 1000 B.P.)	Deterioration in climate coinciding with collapse of the Roman Empire. Cooler wetter climate (Barber, 1982; Lamb, 1995; Hughes *et al*., 2003) landscape and settlement abandonment (Dumayne-Peaty, 1998; 1999). A particulary severe phase was noted at ca. 1100 B.P. (Barber *et al*., 1999).
Mediaeval Warm Period (ca. 1050-650 B.P.)	Trend to warmer more stable climate with land cultivation rising to levels near those seen in the Bronze Age (Lamb, 1984; 1995). Tree rings indicating warmer temperatures (Eronen *et al*., 1999; Briffa, 2000) and reduced catchment erosion and high tree lines (Berglund, 2003).
Little Ice Age (ca. 650 – 200 B.P.)	Climate deterioration characterised by increased storminess and wet weather (Britton, 1937; Lamb, 1995). Coldest years of the last millennium and decades in this period (Jones *et al*., 1998). Increased catchment erosion has also been shown to have occurred in this period (Foster *et al*., 2000).

Table 2.1 Summary of the climate changes since the Bronze Age.

2.3.3 Environmental Change in the English Midlands

The following section summarises the evidence for late Holocene environmental change (ca. 3500 cal B.P. to present) from palynological investigations undertaken in

the vicinity of the site. The vicinity of the site is defined as areas within 50km of Aqualate Mere. This encompasses the English counties of Staffordshire, Shropshire, Worcestershire and Warwickshire.

Woodland Clearance

The landscape of the English Midlands ca. 3500 cal. B.P. was one of relatively dense woodland, but it had recently begun to change. Forest clearance, associated with farming had begun to make inroads at Kings Pool ca. 4170 B.P (Bartley & Morgan, 1990) and Crose Mere ca. 3900 B.P (Beales, 1980). Much woodland remained, but the composition had begun to change (Twigger & Haslam, 1991). The frequency of Elm and Lime trees was much reduced and herb communities began to establish in small cleared enclaves. This also provided the opportunity for light demanding Birch and Ash to establish (Twigger & Haslam, 1991). In amongst this woodland there is evidence for agriculture at Boreatton Moss from 3800 cal. B.P (Twigger & Haslam, 1991) and at Crose Mere from 3900 B.P. (Beales, 1980).

At the beginning of the period represented by the core for this study, agriculture had begun to expand across the region. This may be associated with the favourable climatic regime of this period (Lamb, 1995) which was further evidenced by the expansion of *Tilia* at Kings Pool ca. 4000 B.P. (Bartley and Morgan, 1990). Evidence for this expansion in agriculture is present at Kings Pool (Bartley & Morgan, 1990) and Rushpool and Wilden Marsh (Brown, 1987) in the form of cereal pollen and a rise in indicators of arable land such as *Plantago lancelota*.

Woodland Regeneration

The agricultural expansion appears to have continued until ca. 2800 cal B.P. This correlates with the climatic deterioration indicated around this time (van Geel, 1996; Bond *et al*., 1997; Berglund, 2003; Swindles *et al*., 2007). Evidence from Berth Pool and Birchgrove, in the form of bog moss spores, indicate a shift to a wetter climatic regime around this time (cited in Twigger & Haslam, 1991). There also appears to have been a shift towards higher ground with reduced land use intensity at Crose Mere and

Baschurch, ca 2750 – 2550 cal B.P. (Beales, 1980; Twigger & Haslam, 1991). This period coincides with a recovery of woodland ca 2500 cal. B.P. across Shropshire and Staffordshire (Bartley & Morgan, 1990; Twigger & Haslam, 1991).

Regeneration was not uniform across the region. Twigger and Haslam (1991) indicate that renewed clearance occurred around Birchgrove and Berth Pool ca 2550 – 2350 cal. B.P. Similar to this was almost total clearance of woodland to the south, at Ripple Brook between 2850 and 2350 B.P. (Brown & Barber, 1985). This may have been the result of mechanisms suggested by Dark (2006) discussed in Section 2.32.

Renewed Clearance and Agricultural Expansion

Following this regeneration of woodland there appears to have been widespread clearance in the mid Iron Age (Twigger & Haslam, 1991). Agriculture also appears to have expanded around this time (Beales, 1980; Barber & Twigger, 1987). There is also an increase in the proportion of minerogenic deposition in the mere's of Shropshire around this period, most likely associated with destabilisation of catchment soils (Beales, 1980; Twigger & Haslam, 1991). A second period of woodland regeneration is, however, indicated in parts of the region prior to the Roman period. This has been shown at Crose Mere ca. 2300 B.P. (Beales, 1980) and at Fenmere and Baschurch Pools (Twigger & Haslam, 1991).

The Roman Period witnessed the growth and establishment of arable agriculture across the region from the second century A.D. (Bartley & Morgan, 1990; Twigger & Haslam, 1991). An increasing minerogenic input to a number of the lakes of the Midlands around this time appears to confirm an intensification of agriculture (Beales, 1980).

Historical Times

Following the Roman Period there are few studies of the environmental changes of the Midlands (Pittam, 2006). The exception to this is the study of Crose Mere by Beales (1980). However, the sampling resolution of this study of insufficient quality to infer

any detailed information beyond the continuation of agriculture. This gap in knowledge was justification of the original study of Aqualate Mere by Pittam (2006).

2.4 Chapter Summary

This chapter has sought to highlight the rationale and gap in knowledge that this study aims to address. The following is a list of the principal findings of this literature review:

1. Lakes are excellent sensors and form excellent archives of environmental change by means of accumulating sediments.
2. Diatoms are an excellent tool for reconstructing such changes due to their high sensitivity to a wide range of ecological variables.
3. A suite of techniques are available for dating the past.
4. Holocene climate is inherently variable and imbued with cycles.
5. There is a distinct lack of multi-proxy palaeoenvironmental studies in the English Midlands. More specifically there is a lack of diatom based studies addressing late Holocene environmental variability in the English Midlands.

3.0 Site Setting

3.0 Introduction

This study of the sediments of Aqualate Mere builds upon and utilises the data and work of Pittam (2006). The key aim of the study is to set the diatom reconstructions of this work within the chronological framework established by Pittam (2006). This chapter will firstly provide a brief overview of the site history and context of Aqualate Mere, reviewing previous work. The second part of this chapter will review the data used from Pittam (2006).

3.1 Aqualate Mere

3.1.1 Context

Aqualate Mere is designated as a Site of Special Scientific Interest (S.S.S.I.) and a National Nature Reserve (N.N.R.). Both of these designations relate to the habitats which surround the lake. The site has also been recognised by Glasser (2004), in the Nature Conservancy Council (currently Natural England) Geological Conservation Review, as being of significance due to its importance as a Devensian Glacial Site. As a result of these designations the site itself is managed by Natural England, but is located within the land ownership of the tenants of the nearby Aqualate Hall.

3.1.2 Site Setting

The study site, Aqualate Mere, is located in the English county of Staffordshire at the approximate Ordnance Survey grid reference SJ 771 205. The nearest town is Newport, which lies approximately 2km west and the Wolverhampton/Birmingham West Midlands conurbation lies approximately 28km southeast. Other urban centres

are the town of Stafford, located approximately 18km east, and Telford approximately 16km southwest.

The site lies within an area with a high concentration of historical Roman activity, a great deal of which is still visible in the landscape today (Pittam, 2006). During the Roman period two roads crossed through the catchment, which are still visible on the modern Ordnance Survey Map. One of these roads is the arterial Watling Street, now the A5, which crosses the southern part of the catchment and was the first Roman road constructed in Britain (Roucoux, 1984). Another highly notable piece of Roman activity in the vicinity of the site is the *civitas* of Viroconium Cornovium, modern day Wroxeter, which is located approximately 25km southwest.

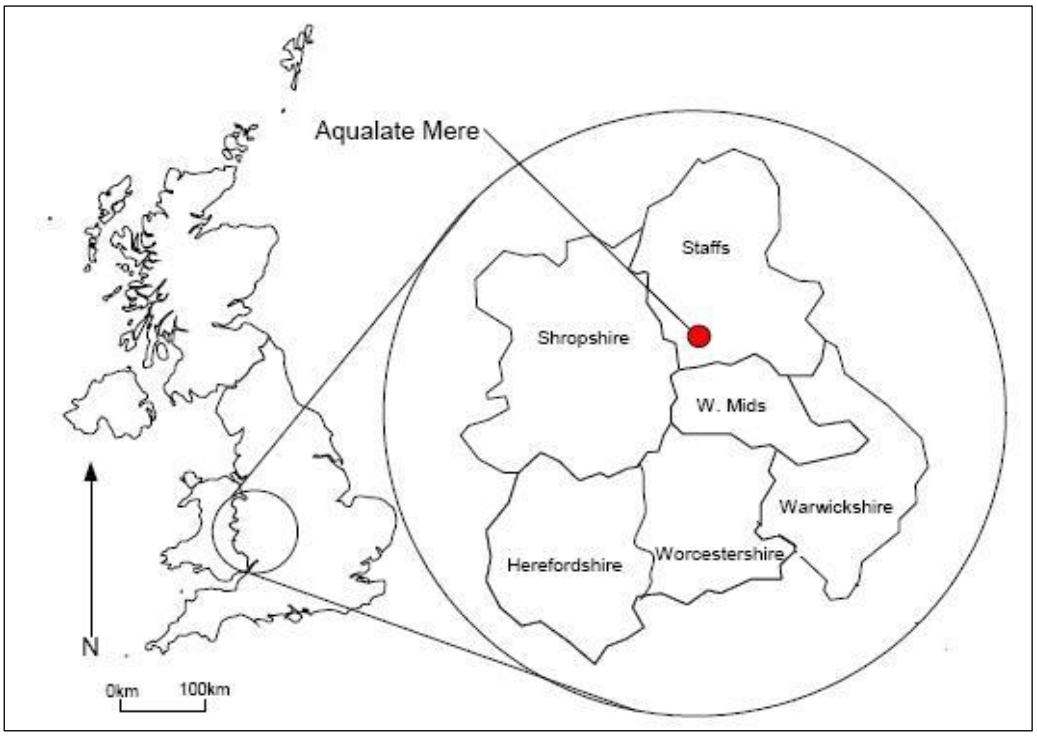

Figure 3.1 Location of Aqualate Mere within the United Kingdom (adapted from Pittam, 2006).

Figure 3.2 Aqualate Mere and the catchment

3.13 Geological Context

The British Geological Survey (B.G.S.) map number 139 solid and drift edition indicates that the site is underlain by the following:

The drift deposits for the site vary to the north, south, east and west. To the north the site is underlain by Glacial Till and to the south by Glacial Sand and Gravel. It is likely that there is a contact between the two underlying the Mere and therefore the underlying drift will be a mixture of the two. These recorded drift deposits are consistent with the assertion of Glasser (2003; 2004), that Aqualate Mere formed from a Kettlehole in Devensian glacial deposits.

Peat deposits, probably of more recent Holocene age, underlie the sections to the east and west with a further area to the south, connected to the Mere by the Back Brook. It is likely that this peat marks the past extent of the Mere overlying the Glacial Sand and Gravel and the Glacial Till. The depth of these deposits is not clear, but it is likely that they represent a full Holocene sequence (Glasser, 2003). The Mere itself was cored to a depth of 12.60m during the work of Pittam (2006), which did not identify the base of these deposits.

The solid geology underlying the drift is recorded as the Wildmoor Sandstone Formation of the Sherwood Sandstone Group of Triassic age. These rocks are indicated to be faulted in a south-west to north-east axis with a down-throw to the north-west. These rocks do not outcrop within the vicinity of the site.

3.1.4 Lake & Catchment Morphology

Aqualate Mere is located within a low lying catchment (ca. ≤80m A.O.D) in the English Midlands. It is a relatively large lake, and the largest within the English Midlands. Measuring approximately 1.5km from east to west and 0.5km north to south the lake has an approximate area of 0.75km^2. Despite the large area the lake is very shallow and has a mean depth of 1.20m with a maximum depth of 1.40m (Pittam, 2006).

Three main tributaries, the Coley Brook, Humesford Brook and Wood Brook enter the lake along the northern and eastern shore. These streams along with a number of smaller agricultural ditches drain a catchment which, at its largest extent, measures 6.35km north to south and 2.60km east to west and encompasses approximately 5924ha. (Hutchinson, 2003). There is a further input to the hydrological system from the Shropshire Union Canal. This, however, was constructed in 1796 and is of little relevance given the time frame of this study. The Mere is not a closed system and there is a major outflow on the western shore of the lake in the form of the River Meese.

3.1.5 Previous Studies

Three previous studies of Aqualate Mere have been undertaken; two palaeolimnological and one hydrogeological. The hydrogeological site assessment was undertaken on behalf of the National Rivers Authority (N.R.A), which now forms part of the Environment Agency and is of little relevance to this study. Of the two palaeolimnological studies, one, by Hutchinson (2003; 2005) focused on the recent palaeoenvironmental history of the Mere ca. 300 years and is also of little relevance.

The second palaeo study is that of Pittam (2006) and it is this study, which this work draws on. Pittam (2006) reconstructed a fossil pollen record from a 4.90m long suite of sediments and undertook a series of environmental magnetism measurements on these sediments. This record was dated using a mixture of radiocarbon, Lead 210 and Caesium 137 along with using stratigraphic markers such as Spheroidal Carbonaceous Particles (S.C.Ps). This chronology provided a calibrated radiocarbon age of 1300-900 B.C. for the base of the core and identified three distinct phases of sedimentation. These phases indicated a relatively slow rate of sedimentation up until the late 18th century and early 19th century when the sedimentation rate dramatically increased. Pittam (2006) identified this change at a depth of ca. 1.38m and attributed the increasing sedimentation to landscaping activities in the nearby Aqualate Deer Park. Further discussion of the results of this investigation will be an ongoing theme of this thesis as the results of this work are integrated with the findings from this current investigation.

4.0 Methodology

4.0 Introduction

4.1 Field Work

As has already been discussed this work builds upon that of Pittam (2006). This investigation utilises the sub-sampled sediment core of that investigation. Additionally the fossil pollen counts and environmental magnetics data that was generated is studied. As a result of this very little fieldwork was necessary to achieve the aims of this study.

4.1.1 Site Walkover

A site walkover was undertaken however to gain a 'feel' for the conditions of the lake and the surrounding landscape. This site visit was undertaken on 17th July 2008 and a number of photographs of the lake and its surrounding environment were taken. Water samples were also collected at this time for possible later analysis. A single sample was taken from each of the major inflowing streams and from the Mere itself. These were to be used to establish the modern diatom assemblages of the various water bodies.

Figure 4.1 Aqualate Mere as it exists today.

4.2 Palaeoecological Laboratory Methods

This section will initially discuss the methods used for extracting, preparing and mounting microfossil slides from the sediment. The method of counting and recording of data is then covered. A discussion of the sampling strategy and issues concerning sampling resolution follows. The work will use sediments collected from a 4.90m long core by Pittam (2006). This core was previously dried, sub-sampled at 1cm intervals and placed within airtight containers. The samples have been stored in the Palaeoecological Laboratories of Coventry University since 2005.

4.2.1 Microfossil Preparation

The preparation of microfossil slides generally followed the method outlined for the preparation of large sets of diatom slides in Renberg (1990). The following is an explanation of principles of the method followed by a description of the protocol. Risk assessments and a simplified flowchart of the protocol are presented in Appendix 1.

The basic principle behind the preparation method lies in the fact that diatoms are composed of a silica cell wall. Given this, the method uses Hydrogen Peroxide to metabolise all other organic matter producing Carbon dioxide and water as by-products. When this reaction is complete the sediment liquid mixture turns a milky white colour leaving only the silica based diatom fossils suspended in a mixture of water and hydrogen peroxide.

The protocol for the method is as follows. A $5mm^3$ sample of sediment was sub-sampled using a 5mm square ended spatula and placed within a test tube. This sample was then immersed in 1ml of 30% Hydrogen Peroxide and placed within a water bath pre-heated to 80°C. A rubber stopper was placed on the lid and the sample left for one hour. After one hour the sample was removed from the water bath, gently shaken, a further 1ml of Hydrogen Peroxide added and left for a further hour. The sample was then checked for a colour change. If the colour was still not the desired milky-white colour then further hydrogen peroxide was added to complete the reaction. Once the reaction was complete the samples were removed from the water

bath and 'topped up' with distilled water to wash and re-suspend the samples. These samples were then placed within a cool room for 48 hours to allow for the differential settling of diatoms and finer particular matter, which could potentially cloud the prepared microscope slide. After 48 hours the supernatant was removed by means of a Pasteur pipette. This liquid was then discarded and the sample transferred to a small storage jar. The storage jar was then further topped up with distilled water in preparation for mounting.

To mount the slides two round cover slips were laid out and an aliquot of the prepared suspension was pipetted onto the first slip; this is a 'concentrated' sample. A second, smaller, aliquot was then taken and pipetted onto the second slide. Additional distilled water was then added to this aliquot to dilute the suspension. The aim of creating two different concentrations was to produce microfossil slides in which the diatoms will be clearly visible when counting. Before this could proceed the samples were left overnight to dry.

Once the samples were dry they were permanently mounted onto microscope slides. The slides were mounted using Naphrax; a highly refractive resin. Two small amounts of this substance were placed onto a microscope slide and the coverslip was gently placed on top. Permanent mounting was achieved by applying heat to the slides through a hotplate at 130°C. This procedure was undertaken in a fume cupboard as Naphrax contains the solvent Toluene, a carcinogen, which is liberated from the resin on heating. The slide was then left for a short period on the hotplate and once removed the resin quickly set leaving the coverslip permanently fixed to the microscope slide.

4.2.2 Microfossil Counts

The microfossil counts represent the core of the data collection of this study. Two types of data were collected in these counts: species abundance data and diatom preservation data. The counts in this study followed the method outlined in Battarbee (1986). The microscope slide was placed under the lens and an aliquot of immersion

oil was placed on the slide. The slides were then viewed under an x1000 objective for counting.

Counts proceed by means of transects through the centre of the slide with all diatoms under the field of vision counted, and identified, first to genus and secondly, to species until 300 individual diatoms were counted. Identification of diatom species was made to examples and nomenclature presented in Foged (1974; 1977); Krammer and Lange-Bertalot (1986; 1988; 1991a & b) and Hartley *et al*. (1996). Batterbee (1986) states that once 300 individuals have been counted then ≥95% of the total species present within the assemblage will have been identified. This is a percentage that is sufficient for the purposes of this investigation. An assessment of the preservation of the valves was also undertaken in the counting process. Fractured valves were only included in the count if more than half of the valve was intact or if the entire central area was intact. A separate tally was also made when fractured values were counted.

4.2.3 Sampling Strategy

The sampling strategy for this investigation followed three phases. The initial phase of sampling began with taking material from the top of the core to a depth of 490cm at an initial resolution of 10cm intervals. The samples were prepared following the method outlined above and initial inspections were undertaken to track diatom preservation through the core.

The initial brief inspection of the slides at this relatively coarse resolution identified a significant decline in fossil preservation from ca. 150cm. Closer inspection revealed that diatom counts were unlikely to be viable above a depth of 130cm. This depth is of significance as Pittam (2006) identified significant changes occurring at this depth. These were explained as being the result of landscaping activities in the Aqualate catchment, which lead to significant erosion and in-wash of sediment to the lake. It is possible that this event may have disrupted the ecology of Aqualate Mere. This could have lead to a collapse of diatom production. Or alternatively these changes may have worked to decrease the chance of diatom fossils being preserved.

Following the discovery of the lack of diatom preservation above 130cm, the focus of the study was refined. Only the section of the core from 490cm to 130cm would now form the basis of this study and the first set of counts were undertaken on the samples at 10cm intervals. A stratigraphic diagram of changes was produced following these counts, which highlighted a number of events of interest. Given the large number of changes it was decided that finer sampling should target the entire core, rather than just specific events. The rationale behind this was that there were too many changes to target, therefore greater resolution of the whole core was required. As a result samples were then prepared to a resolution of 5cm intervals.

The 5cm sampling resolution provided a much clearer sequence of changes to the diatom assemblages. Following analysis and interpretation of these changes it was possible to further refine the stratigraphy with a third phase of sampling. This phase of sampling targeting two major shifts in the microfossil community around depths of 4.60m and 2.30m where two additional samples were examined that surrounded the shifts.

4.3 Data Representation

Diatom stratigraphy diagrams were constructed using TILIA TGView software (Grimm, 1991;2007) and were zoned according to the pollen zoning established by Pittam (2006). Taxa are presented as a percentage of the total diatom assemblage (T.D.A.), counted at each interval studied, and individual x-y scatter-plots are presented for each species. Where a species is a rare type, those, which represent ≤1% T.D.A. the species is omitted from the diagram at that interval. Wherever possible the species were divided into the life form groupings planktonic, tychoplanktonic, epontic and benthic following Denys (1991) and Van Dam *et al* (1994). Lists of the assignments for each species identified are presented in Section 9.5 of the Appendix.

4.3.1 Ecological Indices

Diatoms make excellent sensors of environmental changes due to their high specificity to a number of ecological variables included nutrient levels, salinity and pH (Dixit *et al*,

1992; Stoemer & Smol, 1999). Using these data qualitative ecological indices have been constructed for each of the variables. These are based on the ecological requirements of diatom species observed, recorded and compiled in Denys (1991) and Van Dam *et al* (1994). They have been constructed to provide a general overview of what the diatoms indicate. In each index an increase in the value indicates an increase in the variable represented. These indices are however, strictly qualitative and the numbers do not reflect actual values for pH, salinity or trophic status. The following section outlines how these indices were constructed and the constructed indices are presented in Chapter 5.0. A list of the assignments for ecological preferences of each diatom species identified in presented in Section 9.5 of the Appendix.

4.3.2 Indices

The construction of these three indices was broadly the same. The following section illustrates how the indices were constructed with reference to the trophic index.

Denys (1991) and Van Dam *et al* (1994) assigned a standardised trophic status. The nomenclature eutrophic, mesotrophic to eutrophic, mesotrophic, mesotrophic to oligotrophic and oligotrophic were used classify diatoms based on the type of water body the species have been previously recorded in. Unfortunately the ecological gradients of classifications are not defined and hence, are somewhat arbitrary, but they work as crude indicator in the absence of transfer functions.

To construct the Trophic index used in this study it was first necessary to classify all the diatom species, where possible, to these trophic levels. Each of the different levels were then provided with a score from 5 to 1, with 5 being eutrophic and 1 being oligotrophic. A spreadsheet was then constructed, which placed each calculated score for the diatom assemblage at each of the sampling intervals. This worked on the principal thus; the abundance of species at each level was counted and multiplied by the relevant score for the trophic level. This was carried out on each trophic level and the total score was calculated. This score was then divided by the number of individual taxa that had been counted. This number did not always equal the full count of 300 as data was not available of the trophic requirements of all species, and

the indices reflect this. The resulting number then provided the trophic score for that interval of the core. These trophic scores were then plotted in an x-y scatter-plot against the core depth to provide an indication of how the trophic status of the lake varied through time.

The process for the construction of the trophic index was repeated for the construction of the pH and salinity indices.

4.4 Previous Analyses

This work utilises a number of the datasets generated by Pittam (2006) and makes use of the chronology established in that work. The following is a list of the analyses, which were generated from that work and are reproduced in this study:

- Elements of the historical pollen stratigraphy.
- Elements of environmental magnetism data.
- Loss on Ignition (L.O.I.) data.

4.4.1 Core Chronology

The work that was undertaken to establish the chronology of the core was not all required for this study. Radiocarbon dates were utilised along with the record of Spheroidal Carbonaceous Particles (S.C.Ps). Given that this study does not focus on the results from above a depth of 130cm it was not necessary to utilise the chronology provided by Lead 210 and Caesium 137 dating techniques, which were taken from sediments above the SCP date. The elements of the chronology used in this study are presented below in Table 4.1 and an age depth plot is presented in Figure 4.2.

Depth of Sample (cm)	Method of analysis	Dates		Lab number or analyser
		Conventional (years B.P)	Calibrated (years)	
113	S.C.P	N.A.	A.D. 1830	Pittam (2006)
245	Radiocarbon	1530 +/- 70	A.D. 280-440	AM 245 Beta-183241
489	Radiocarbon	2900 +/- 70	B.C. 1300-900	AM 485 Beta-184151

Table 4.1 Pittam's (2006) chronology.

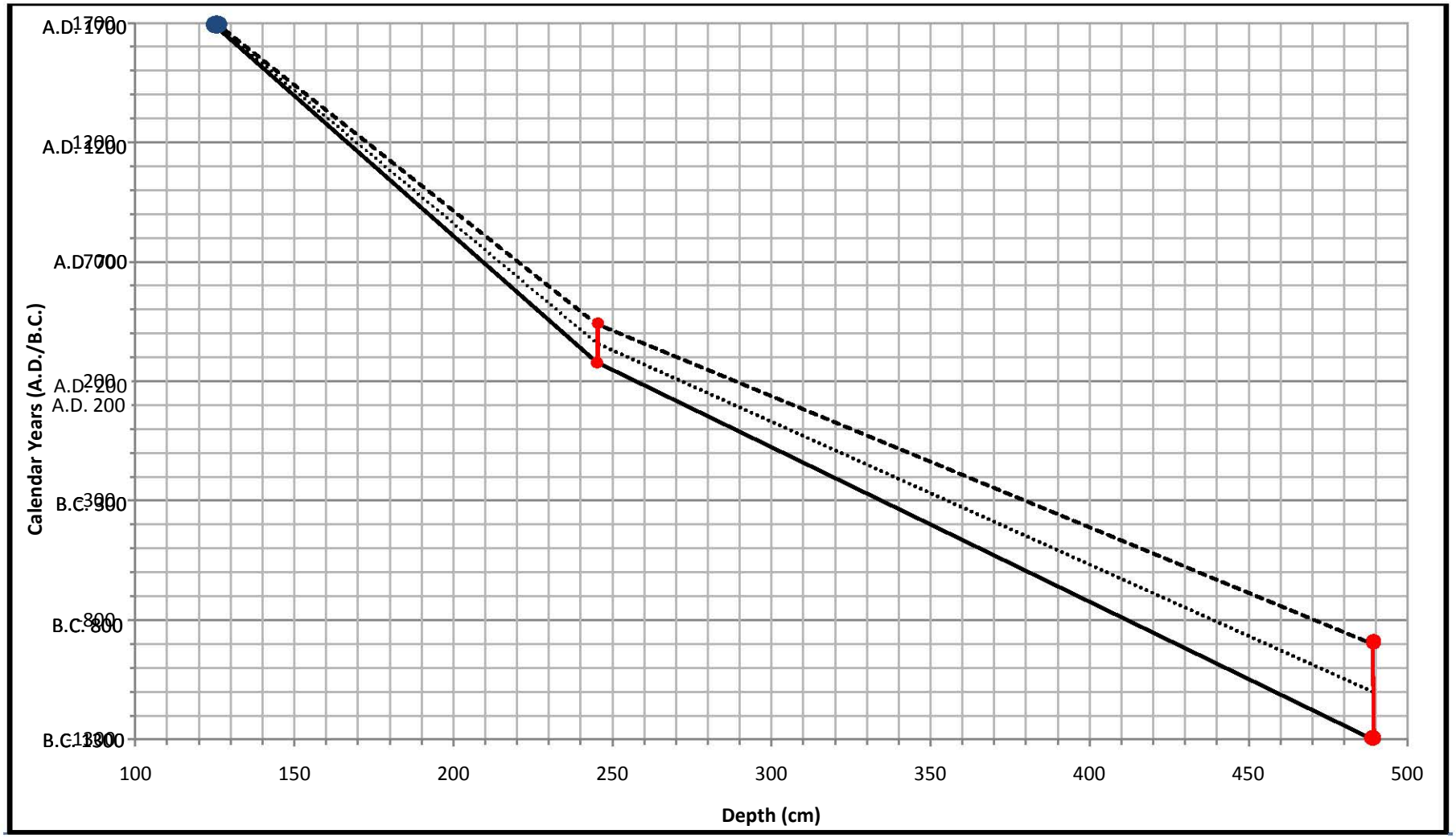

Figure 4.2 Age depth plot for Aqualate Mere. Calibrated radiocarbon date ranges are presented with red dots and connecting lines, with the SCP date represented by a blue dot. The thick (lower) line indicates the oldest possible dates of the samples and the dotted (upper) line indicates the youngest possible dates of samples. Sample dates have been connected, with the assumption of a constant rate of sediment accumulation to provide a time envelope of dates for the depth of the core.

5.0 Results Analysis

5.0 Introduction

The following chapter presents and analyses the results of the diatom based qualitative reconstructions. Diatom inferred qualitative reconstructions of pH, trophic status and lake salinity are presented alongside diatom life form reconstructions and preservation. These results are then analysed alongside selected elements of the pollen and environmental magnetism measurements of Pittam (2006). Diatom reconstructions have been zoned in accordance with pollen zones established by Pittam (2006).

Since changes in pollen are predominately the result of anthropogenic activity the diatom reconstructions have been placed within this framework. This will help fulfil objective 1: to establish if there are links between land use changes, and changes in the diatom assemblage.

The following pages will present the diatom inferred reconstructions (the data upon, which the reconstructions are based in presented in the Appendix) and will be followed by analysis of the changes through each of the relevant pollen zones. This analysis will seek only to describe the general trends observed in the data and hence highlight any links between land use change and diatom stratigraphy. Some limited discussion of the possible causes or consequences of such change will be presented as appropriate. However the majority of the discussion of causes for such changes will be undertaken in Chapter 6. Figure 5.0 below summarises the pollen zones.

Pollen Zone	AM 1	AM 2	AM 3	AM 4	AM 5	AM 6
Depths (cm)	490 - 448	448 - 395	395 - 365	365 - 268	268 - 251	251 - 142
Extrapolated dates (cal. calendar yrs)	1100 - 850 B.C.	850 - 530 B.C.	530 - 350 B.C.	350 B.C. - 220 A.D.	220 A.D– 325 A.D.	325 A.D. – 1500 A.D.

Table 5.1 Depths and extrapolated dates of the Pollen Assemblage Zones.

5.0.1 Diatom Inferred Reconstructions

The following are the diatom inferred reconstructions of pH, trophic status, salinity and life forms. Together with these, a composite of species preservation, diversity and loss on ignition is presented. A glossary of the terms used is presented following the graphs in Table 5.2 and the raw data for these reconstructions in presented in Section 9.5 of the Appendix.

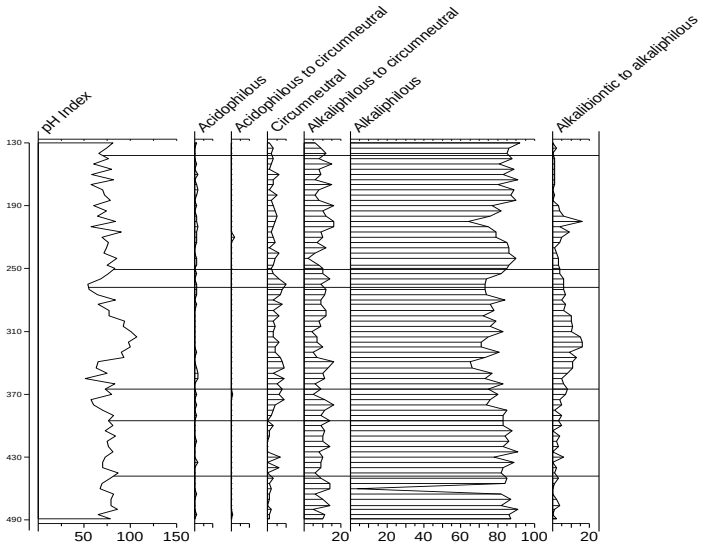

Figure 5.1 Diatom inferred qualitative pH reconstructions. Graphs displayed from left to right: constructed qualitative pH index (rising values indicate rising alkalinity), followed by actual recorded frequencies of each pH habitat. (Data used to construct this figure is presented in Section 9.5 of the Appendix)

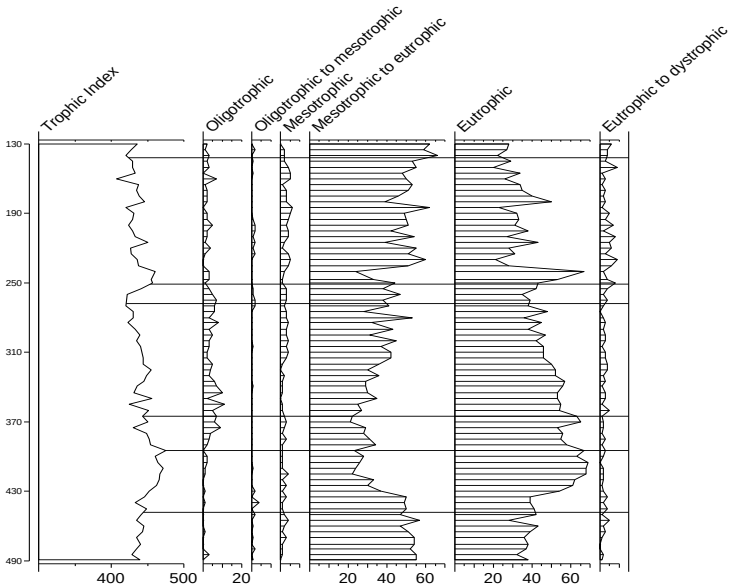

Figure 5.2 Diatom inferred qualitative trophic status reconstructions. Graphs displayed from left to right: constructed Trophic index, followed by actual recorded diatom frequencies of for each trophic level. (Values in trophic index: 300 = mesotrophic and 500 = eutrophic). Data used to construct this figure is presented in Section 9.5 of the Appendix)

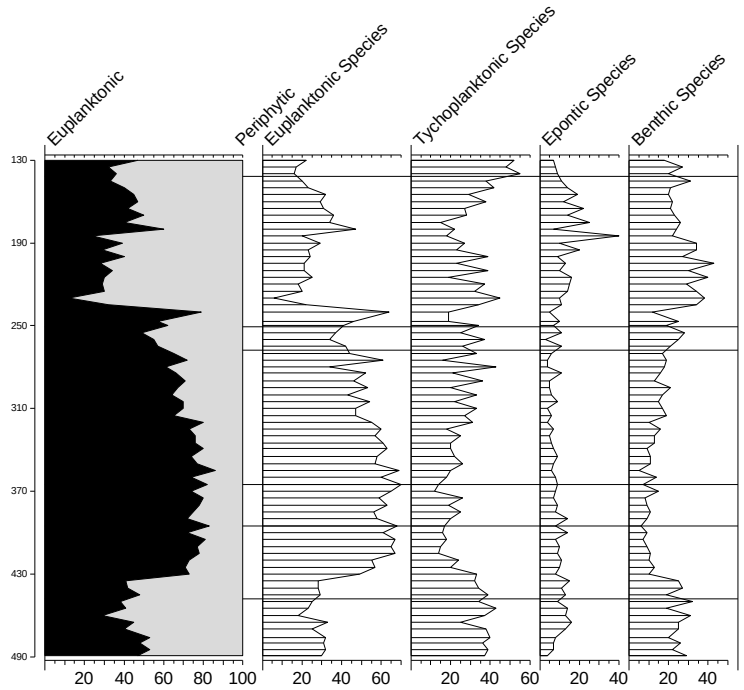

Figure 5.3 Reconstructed diatom life forms, including planktonic/periphytic ratio (periphytic includes benthic and epontic species) and species preservation. Data used to construct this figure is presented in Section 9.5 of the Appendix)

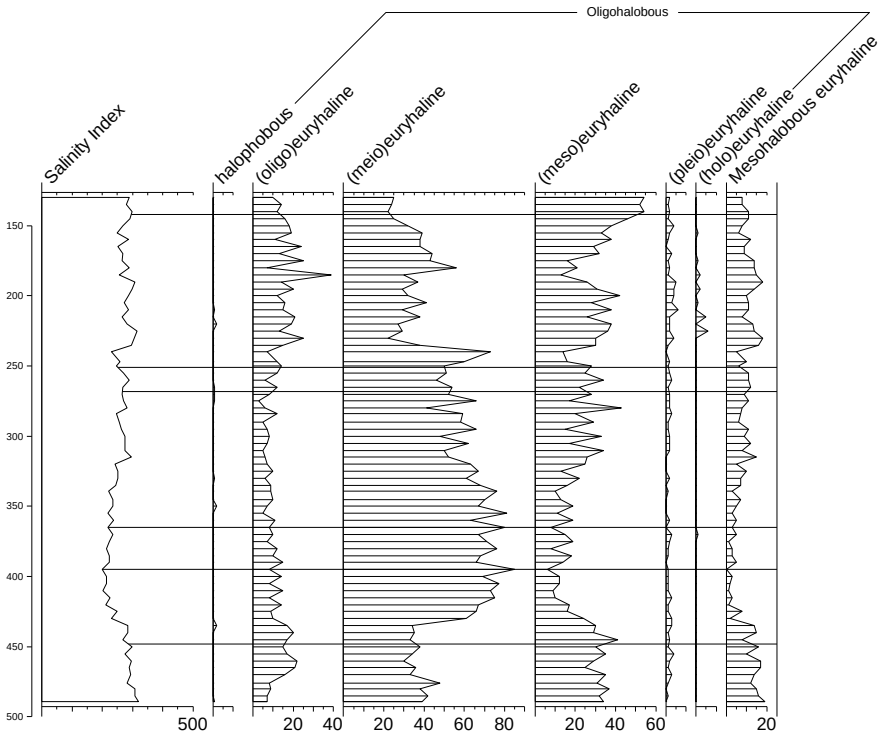

Figure 5.4 Diatom inferred qualitative salinity reconstructions. Graphs displayed from left to right: constructed Salinity Index, followed by actual recorded diatom frequencies for salinity preferences. Data used to construct this figure is presented in Section 9.5 of the Appendix)

Salinity Terms (Hustedt, 1953; Simonsen, 1962; Denys, 1991)	
Term	**Definition**
Mesohalobous euryhhaline	diatoms favouring brackish waters, bays and river mouths, but able to adapt to a wide range of saline conditions.
Oligohalobous (holo)euryhaline	optimum development conditions are in freshwaters, but comfortably adapt to a wide range of saline conditions.
Oligohalobous (pleio)euryhaline	optimum development conditions are in freshwaters, but tolerant of highly saline conditions.
Oligohalobous (meso)euryhaline	optimum development conditions are in freshwaters, but will tolerate an intermediate level of salinity
Oligohalobous (meio)euryhaline	optimum development conditions are in freshwaters, but will tolerate an intermediate to low level of salinity
Oligohalobous (oligo)euryhaline	optimum development conditions are in freshwaters, but the species will tolerate slightly saline conditions
Oligohalobous halophobous	optimum development conditions are in freshwaters and these species are saline intolerant
pH Terms (Hustedt, 1937-39; Denys, 1991)	
Acidophilous	Diatom species with a preference for slightly acid conditions (pH 6-7)
Circumneutral	diatom species with a preference for strictly neutral waters (ca. pH 7)
Alkaliphilous	diatom species with a preference for slightly alkaline waters (pH 7-8)
Alkalibiontic	diatom species with a preference for alkaline water (> pH 8)
Life Forms (Round *et al*., 1990)	
Euplanktonic	are free floating diatoms of open water and exist in suspension throughout their lifecycle
Tychoplanktonic	these a species that are accidently carried into the plankton by factors such as turbulence. They are equally at home in planktonic environments or in benthic or epontic environments
Epontic	these are diatoms, which live attached to sediments, rocks or plant matter at or near to the bottom of a body of water
Benthic	the benthos are diatom species which live freely in the sediments at the bottom of a water body
Peripyhtic	the periphyton as referred to in this study is a combination of the diatom species dwelling at or near to the bottom of the water (combination of the epontic and benthic species).

Table 5.2 Glossary of terms used in Figures 5.1 - 5.4

5.0.2 Others

The following are a selection of pollen and environmental magnetics data from Pittam (2006). The pollen data has been selected on the basis of their use as indicators of landscape changes such as agricultural impacts and clearance events. The magnetics data presented has been selected on the basis of measurements that show significant variation throughout the core. A glossary explaining the significance of these measurements is presented in Table 5.3.

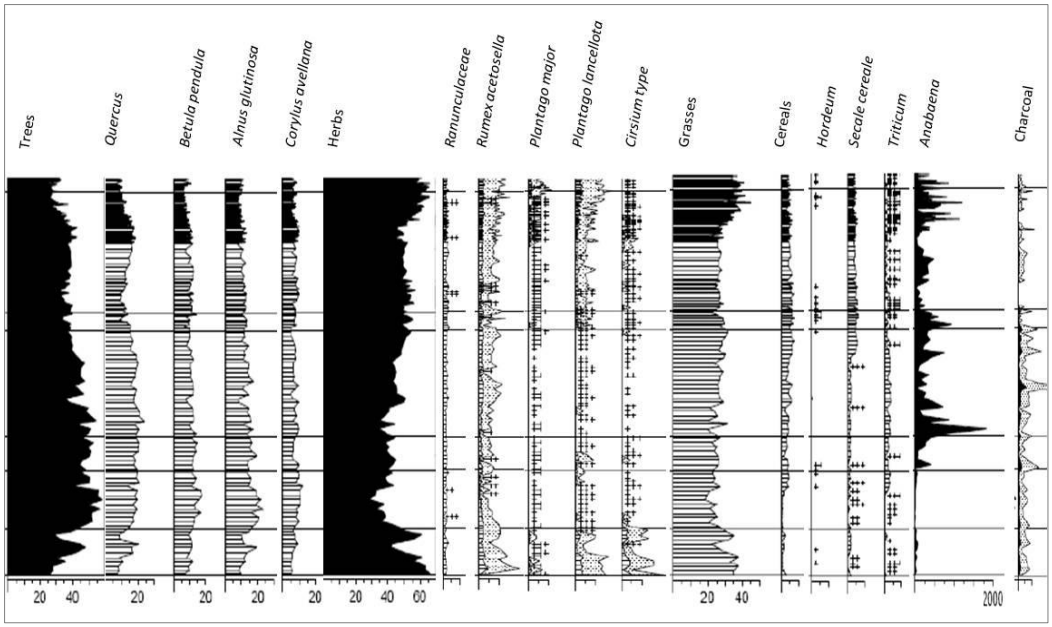

Figure 5.5 Selected pollen reconstructions, including cereals, trees, grasses and other indicator species.

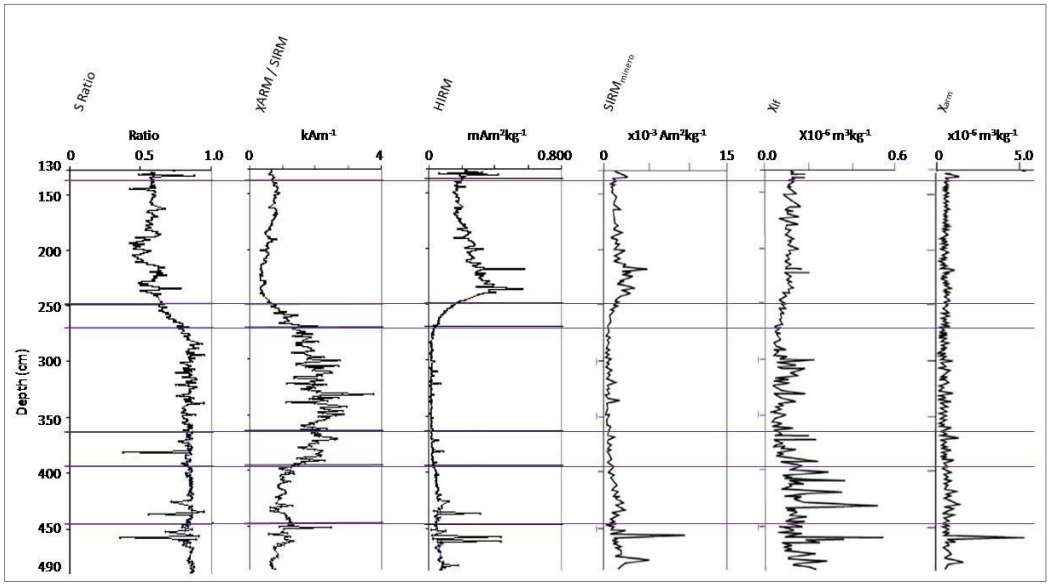

Figure 5.6 Environmental magnetism measurements (adapted from Pittam, 2006).

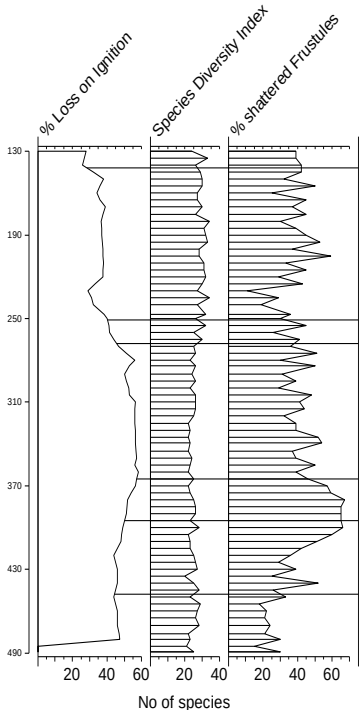

Figure 5.7 Species diversity index, Loss on Ignition (after Pittam, 2006) and diatom preservation record.

Parameter	Description
HIRM (Hard isothermal remanent magnetism)	is used to quantify the absolute quantity of antiferromagnetic minerals (haematite and goethite) within a sample. Rising values indicate increasing presence of antiferromagnetic minerals (Walden, 1999).
S-Ratio	is used to quantify the relative quantity of antiferromagnetic minerals. It is a measure of ratio between anitferromagnetic minerals and ferromagnetic minerals, such as magnetite with decreasing values indicative of increases of antiferromagnetic minerals (Dearing, 1999).
χlf	provides information on the concentration of ferromagnetic minerals or the total concentration of paramagnetic and antiferromagnetic minerals. The values range from -0.01 to ca. 1,000 x 10^{-6} m^3 kg^{-1} in samples that have high values associated with ferrimagnetic minerals, basic/ultrabasic rocks and burned soils. Sedimentary rocks range from ca. 0.001 to 0.1 9 10^{-6} m^3 kg^{-1} while metamorphic and igneous rocks produce intermediate values (Dearing, 1999; Foster et al., 2008)
$SIRM_{minero}$ (soft isothermal remanent magnetism)	is the highest amount of magnetic remanence that can be produced in a sample and is a measure of the remanence carrying material in the sample. Ferromagnetic Minerals such as magnetite will be fully saturated in such a field and increases in $SIRM_{minero}$ are indicative of such minerals (Walden, 1999).
χARM (anhysteretic remanent magnetism)	is indicative of a sample dominated by true stable single domain ferrimagnetic grains especially those between 0.025 and 0.1 lm diameter, when the grains are grains outside this range, the value decreases significantly (Walden 1999).
χARM/SIRM	relates to magnetic grain size and would be expected to decrease as coarser magnetic grains dominate a sample. A change in this ratio in a lake sediments can be indicative of dissolution diagenesis, which acts to selectively remove finer magnetic grains from an assemblage. This measurement can also be used as an indicator of bacterial magnetosomes activity with values of 2 x 10^{-3} mA indicative of such activity (Oldfield *et al*., 1999).

Table 5.3 Glossary and significance of magnetic measurements.

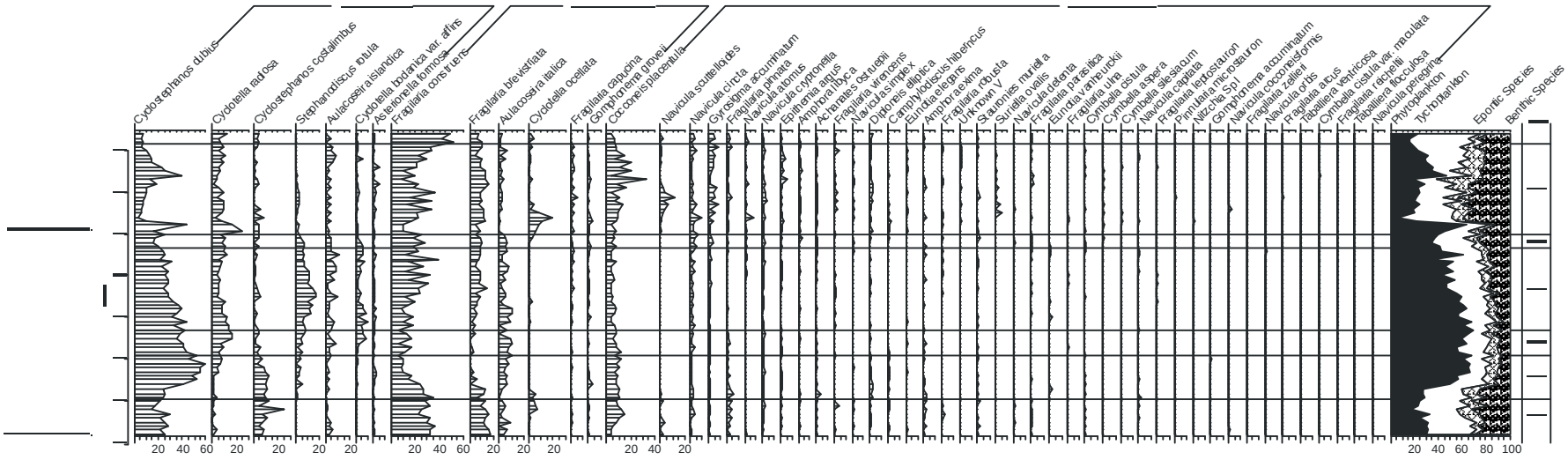

Figure 5.8 Diatom taxa counted from Aqualate Mere including radiocarbon dates and pollen assemblage zones of Pittam (2006)

5.0.3 Core Chronology

As was discussed in section 4.4.1 the core chronology is based on dating undertaken in the work of Pittam (2006). All dates quoted from this point forward are the median point of the time envelope constructed in Figure 4.2. They are based upon extrapolation, which proceeded via the assumption of constant sedimentation between known dates and as such they are approximate and should be treated with caution (see Figure 4.2).

5.1 Zone AM1 490cm – 448cm

The period represented by Zone AM1 spans the dates ca. 1100±200B.C. to 850±190B.C. This places the zone as a transitional zone, probably in the late Bronze Age.

5.1.1 Indices and Indicators

The trophic index (Fig 5.2) begins the zone at 438 and immediately sharply decreases to 425, the lowest value for the zone. The index then fluctuates before reach zonal maximum of 440 at 460cm. Associated with this peak in the trophic index is a peak in the contribution of eutrophic to dystrophic diatoms at 5% of the Total Diatom Assemblage (T.D.A.). Following the peak the index once again decreased before ending the zone at 440. These data indicate a meso-eutrophic, almost eutrophic, water body, something which is supported by the dominance of meso-eutrophic taxa, 47% - 57% T.D.A.

The findings of the trophic index are further supported by the pH index (Fig. 5.1). This ranges from between 65 and 78 which indicates a broadly alkaliphilous environment common in meso-eutrophic water bodies (Smol, 2002; Johnson *et al*, 2003). The composition of the diatom species is also broadly alkaliphilous at ≥70% T.D.A. The only change in this trend occurs at 460cm where the contribution falls to 59% T.D.A. and the circumneutral contribution increases slightly.

The zone is broadly dominated by periphytic species (see Fig. 5.3) with the ratio planktonic to periphytic species ranging from 47:53% to 40:60%. These data suggest a relatively shallow, or clear, water body whereby the photic zone reaches sufficient depths to allow for a relatively large periphytic habitat. The only exceptions are when the ratio switches to slightly favour plankton ca. 485cm, and at 460cm where the periphytic species dramatically expand reflected in the ratio 29:71%. This shift, at 460cm, towards a large periphytic contribution suggests either further decrease in water levels or a disruption to the water column. Diatom preservation is relatively constant throughout the zone with total shattered valves ranging from 15% - 33%. The peaks in shattered diatoms (Fig. 5.7) are at 480cm and at the end of the zone where fracturing reaches 33%. This would seem to indicate a relatively low energy environment where there is little disruption to the diatom valves following their post mortem deposition.

5.1.2 Planktonic Species

Planktonic species consistently contribute between 25% and 33% T.D.A. until the end of the zone where they reach a minimum contribution of 18% T.D.A.

The dominant species through this period is *Cyclostephanos dubius* which begins the zone representing around 20% T.D.A. This steadily climbs to a maximum of 27% T.D.A. in the zone at 465cm before contracting to a minimum of 11% T.D.A. at 460cm. This sudden decrease in *C. dubius* is concurrent with a sharp peak in *Cyclostephanos costatilimbus*, which reaches a maximum of 26% T.D.A. at this point. No autecological data is available on *C. costatilimbus* and it has been included as plankton based on the behaviour of other members of the *Cyclostephanos* genera. Following this minima *C. dubius* once again begins to steadily climb in a linear fashion whereupon it reaches 22% T.D.A. at the end of the zone. As mentioned in 5.1.1 these changes possibly represent decreasing lake levels or an influx of sediment disrupting the water column. However this is merely speculation given the lack of autecological data for *C. costatilimbus*.

Five other planktonic diatoms are present in the zone; these are *Cyclotella radiosa, Stephanodiscus rotula, Cyclotella bodanica var. affins, Asterionella Formosa* and *Aulacoseira islandica*. Each of these species, with the exception of *Aulacoseira islandica*, shows a slight tendency to increase through the zone, but the abundance of any of these species never rises above 3% T.D.A. As mentioned previously *A. islandica* does not follow this trend; starting the zone at 5% T.D.A. it steadily decreases until it is disappears at 460cm (see Fig. 5.8). This is concurrent with the *C. dubius* minima and *C. costatilimbus* peak. After this point *A. islandica* briefly peaks again before disappearing once more by the end of the zone.

5.1.3 Tychoplanktonic Species

Tychoplanktonic species are a major component of the diatom assemblage of the zone. They consistently contribute between 34% and 43% T.D.A. except at 465cm where there is a significant decrease to ca. 25% T.D.A.

The dominant species throughout this period is *Fragilaria construens* which begins the zone representing ca. 30% T.D.A. and undergoes a steady stepped decline reaching a low of 17% T.D.A. at a depth of 460cm. From this point *F. construens* once again begins a steady stepped recovery where it reaches a peak of 31% T.D.A. at the end of the zone. The second most prevalent species is *Fragilaria brevistriata*, which displays a similar pattern to that of *F. construens*.

Aulacoseira italica, a heavily silicified diatom, begins the zone at 3% T.D.A. before doubling to 7% T.D.A only to disappear from the record at 480cm. Immediately following this disappearance *A. italica* returns to the record at an abundance of 8% T.D.A. before once again steadily declining to 1% at 465cm after which the species once again begins a recovery reaching 5% T.D.A. A significant shift in the diatom assemblage was noted in the planktonic diatoms at 465cm to 460cm and is also noted in the species *Cyclotella ocellata*, a tychoplankton originating in benthic environments (Denys, 1991) which appears in the record at an abundance of 5% T.D.A at this depth. *C. ocellata* then begins to steadily decline towards the end of the zone.

5.1.4 Periphytic Species

There are thirty four periphytic species present within the total diatom assemblage (see Fig. 5.8), the majority of which are present throughout the core in negligible concentrations. The periphytic contribution to the T.D.A. ranges between 28% and 45% T.D.A., which is achieved at the depth of 460cm. This depth has been demonstrated by the planktonic and tychoplanktonic species to be a period of change.

The dominant diatom within the zone is the epontic species *Cocconeis placentula*. This species begins the zone at 3% rising to a peak of 14% T.D.A. at the depth of 465cm. Peaks in the diatoms *Fragilaria robusta* and *Navicula cincta* of 2% and 3% T.D.A. respectively also occur at this depth before they both decline along with C*. placentula* towards the end of the zone. Concurrent with these peaks at 465cm to 460cm are minima in the species *Camphylodiscus hiberncus*, *Navicula scutteloides*, *Navicula atomus*, *Navicula Cryptonella* and *Epithemia argus*. Peaks in each of these species are also noted preceding and following this minima the most intense of which, 3% T.D.A. at 4.55m, are in *N. cryptonella*.

The remainder of the periphytic diatoms in this zone exhibit more steady behaviour. The exceptions being the species *Achnates ostreupi* and *Amphora exima* which display a number of small peaks throughout the zone, along with *Fragilaria virencens* which peaks at 455cm. This peak may be of significance as *F. virencens* is associated with dystrophic waters, which are those saturated with suspended organic matter (Smol, 2002).

5.1.5 Correlations

The main findings from the diatom data in AM1 indicate that Aqualate Mere was broadly meso-eutrophic, with a trend towards becoming more eutrophic. The diatom data is supported in this respect by the Loss on Ignition (L.O.I.) data (Fig. 5.7). The L.O.I. shows that the organic concentration of the sediments ranges from ca. 55% at the beginning of the zone to 45% at the end of the zone, indicating high organic content. The assessment of salinity and pH indicate a broadly alkaline environment,

dominated by relatively salt intolerant species, trending towards decreasing salinity. Furthermore the lake was predominately populated by periphytic species, which showed a major expansion in numbers at 460cm ca. 920 ± 180B.C.

In the main part there does appear to be suggestions of a correlation between changes in the pollen record and those of the diatom record. The most striking of these is the shift in the planktonic to periphytic ratio ca. 460 to 455cm. Around these depths the pollen record indicates a major contraction in the arboreal component of the total pollen assemblage from 50% to 30% T.L.P. Correlations around this time are also obvious in the environmental magnetic measurements. Saturated Isothermal Remnant Magnetism (SIRM), Anhysteretic Remnant Magnetism (ARM) and the High Isothermal Remnant Magnetism (HIRM) all peak ca. 460cm (Fig 5.6). This is congruent with the *C. costatilimbus* peak, *C. dubius* minima and apparent shift towards periphytic species.

The close association of the events would appear to suggest catchment changes as a causal mechanism for changes in palaeoecology. This would appear to support the assertions of Roberts (1998); Barber et al. (1999) and Anderson (2000) that by the Bronze Age lakes in the U.K. are predominately influenced by anthropogenic forces.

5.2 Zone AM2 448cm – 395cm

The period represented by Zone AM2 spans the dates ca. 850 ± 180 B.C. to 530 ± 150 B.C. This places the zone as a transitional zone, probably between the late Bronze and early Iron Age.

5.2.1 Indices and Indicators

The trophic index (Fig. 5.2) initially starts the zone by falling then steeply climbing to reach a value of 468 at 420cm. Following this the index declines slightly before rising to a core peak of 471. Once again this trophic data indicates meso-eutrophic water. The rise in the trophic index is attributable to the development of a large contribution from eutrophic species at the expense of meso-eutrophic tax. Eutrophic taxa rise from

39% T.D.A. at the beginning, to dominate at 67% T.D.A at the end of the zone. This assessment of the lake being nutrient rich and slowly becoming more so is supported by the pH index. The pH index (Fig. 5.1) remains relatively constant throughout the zone, with the index ranging from 87 at its maximum to 73, indicating a broadly alkaliphilous water body.

The assessment of the diatom life forms present within Aqualate Mere during AM2 indicates a dramatic shift. The zone begins with the planktonic/periphytic ratio (Fig. 5.3) at 40:60%, indicating periphytic dominance, which continues until 430cm. At this depth a major shift occurs and the planktonic/periphytic ratio shifts 73:27%. The ratio continues this shift towards planktonic dominance, peaking at 83:17% at the end of the zone. This major shift would appear to indicate a rise in the lake levels; or at the least alterations to the mixing regime affecting the extent of the photic zone, thereby decreasing periphytic habitats (Wolin & Duthie, 1999). Evidence from the salinity index (Fig. 5.4) however would appear to support the idea of increasing lake levels. From the beginning of the zone to the end, the index decreases sharply from 298 to 200 indicating decreased salinity. This is reflected in the expansion of oligohalobous (meioeuryhaline) taxa at the expense of mesohalobous (holoeuryhaline) taxa. Decreasing salinity could be a signal of dilution by means of increasing freshwater input and by proxy increasing water levels. It may also be that this is a climate signal of increased freshwater input via direct precipitation (Gaillard *et al.*, 1991)

The preservation of diatoms in zone AM2 shows a major shift towards decreasing preservation. Fractured valves increase from 26% T.D.A. to 66% T.D.A. by the end of the zone. This dramatic shift towards decreasing preservation would appear to indicate an increasingly high energy environment, potentially associated with deteriorating climate.

5.2.2 Planktonic Species

The environment within and or around Aqualate Mere is clearly undergoing significant change through this period. As has already been established the planktonic/periphytic ratio dramatically shifts to a diatom assemblage dominated by plankton. The

planktonic contribution to the T.D.A. rises from 29% at 448cm to 68% at the end of the zone at 395cm.

The dominant planktonic species in this zone is once again *C. dubius,* which is a eutrophic favouring species (Denys, 1991; van Dam, 1994). This species continues a sustained rise, which began towards the end of the previous zone. The growth is generally linear however between 435cm and 425cm the contribution rises from 22% to 46% T.D.A. This is a dramatic shift; not replicated by any other species throughout the core. From this point *C. dubius* continues to grow, with a mixed pattern of fall back and recovery until it reaches a peak contribution of 56% T.D.A. at 405cm. This is the apogee for this species and immediately following this peak the species declines.

Four other planktonic species show patterns of growth through this zone. The species *C. radiosa*, *S. rotula*, *A. islandica* and *C. bodanica var. affins* all rise from near absence at the beginning of AM2. By the end they have reached respective contributions of 7%, 3%, 5% and 2% T.D.A. Each of these species with the exception of *C. bodanica var. affins* are eutrophic favouring taxa (Denys, 1991; van Dam, 1994). Autecological data on *C. bodanica var. affins* however is contentious. The nutrient requirements of the species have been variously described as oligotrophic (van Dam, 1994; Stevens & Dean, 2008), mesotrophic (Propenko *et al*., 2007) and unknown (Bradbury, 1997). Furthermore it has been shown to favour warm conditions associated with water column stratification (Stevens & Dean, 2008) and cold moist climates (Bradbury, 1997; Propenko, 2007). Of further interest is the association the species has shown with heavy metal polluted lakes. This suggests if not a preference, a tolerance for such conditions (Austin & Munteau, 1984; Austin *et al*., 1985; Deniseger *et al*., 1986).

Of the remaining planktonic species *C. costatilimbus*, which showed a pronounced peak in the previous zone begins a pattern of decline from 13% to 4% T.D.A. at the end of the zone. This decline is only briefly interrupted by a shallow peak of 12% T.D.A. midway through the zone at 420cm. This brief peak coincides with that of another planktonic species: *A. formosa*, a eutrophic taxa (Denys, 1991), which begins the zone absent and climbs to a small peak of 2% T.D.A. at 420cm before disappearing from the record by the end of the zone.

5.2.3 Tychoplanktonic Species

The contribution of tychoplanktonic species (see Fig 5.8) during AM2 shows a pattern of gradual decline. At the beginning of the zone tychoplankton contribute 39% of T.D.A. before declining to 17% T.D.A. at 395cm.

There are two main stories for tychoplankton behaviour in this zone: decline and growth. The two *Fragilaria* species: *F. construens* and *F. brevistriata* both decline, to their lowest recorded contributions throughout the entire core. *F. construens* declines to 6% T.D.A. and *F. brevistriata* disappears. *A. italica* shows a sustained period of growth: starting from absence at the beginning of the zone to a peak core contribution of 10% T.D.A. by the end. This event is significant as *Aulacoseira* species, including *A. italica*, have frequently been associated with high energy environments and eutrophic environments (Bradbury, 1975). This association arises from their thick cell wall, which makes the genera relatively heavy compared to other diatoms. Consequently the genera require a relatively turbid, high energy environment to keep them established within the water column. The preservation index for AM2 indicates an increasingly high energy environment; a conclusion the increasing presence of this species would seem to support.

Of the remaining tychoplanktonic species there is little activity. *C. ocellata*, which had peaked just prior to the end of the previous zone, once again peaks at 5% just after the beginning of the zone before disappearing from the record. *G. grovei* also peaks in the zone where it reaches 3% T.D.A. at 430cm before also disappearing from the record.

5.2.4 Periphytic Species

As was established in the planktonic/periphytic ratio the frequency of periphytic species declined markedly throughout this zone. The contribution at the beginning representing 32% T.D.A. where they rise to a peak contribution of 41% at 435cm before collapsing to 14% T.D.A. by the end of AM2.

The dominant species is once again *C. placentula* which maintains a contribution of between 5% and 10% T.D.A. throughout the entire zone. Alongside *C. placentula* are *N. cincta* and *F. pinnata* which contribute a steady 1% to 2% and 1% to 3% T.D.A. respectively. *F. pinnata* reverses this trend slightly when it peaks at 5% T.D.A. at a depth of 440cm near the beginning of the zone. There are also minor peaks in other species such as *A. ostreupi* at 440cm, *D. ellpitica* at 435cm, *C. hiberncus*, twice, at 420cm and 395cm, *N. cryptonella* at 415cm and *N. simplex* at 410cm. All of these peaks however represent no more than 2% T.D.A. respectively reflecting the low contribution of periphytic species throughout the zone AM2.

5.2.5 Correlations

The main findings from AM2 indicate that Aqualate Mere was strongly meso-eutrophic, but became dominated by eutrophic taxa; up to 69%. This is something which is supported by the L.O.I., which rises from 45% to 52% through AM2, indicating increasing organic content (See Fig. 5.7). The pH of the lake again remains remarkably stable and is broadly alkaline while salinity is indicated to decrease substantially. The life form data indicates that the lake was dominated by plankton: up to 70% T.D.A. Inferences from the pollen and magnetics data suggest a period of stability in the catchment. Arboreal pollen and the level of cereal pollen decreases sharply suggesting a reduced human impact. This would appear to be confirmed by the relative stability of magnetic signatures (Fig. 5.6), with the exception of small peaks near the beginning in HIRM and $SIRM_{minero}$. The diatoms appear to be responding in concert or with a slight lag to the changes in the pollen record. This would once more suggest that human changes in the catchment drive change in the ecology of the Mere. Another possibility is that the changes are climatic signals filtered through the effects on human populations. Equally the apparently increasing lake levels, decreasing salinity, decreased diatom preservation and appearance of *Aulacoseira* species could be direct signals of increased precipitation and windiness; associated with a deteriorating climate. It could also be argued that the increasing trophic status is a climate signal driven by strong mixing of the lake due to increased windiness. The events described occur ca. 750 ± 170 B.C., which has been shown to be a period of deteriorating climate (van Geel, 1996; Swindles *et al*., 2007; Plunkett & Swindles, 2008).

5.3 Zone AM3 395cm – 365cm

Zone AM3 is indicated from the radiocarbon dating to most likely lie in the mid Iron Age between the extrapolated dates of 530 ± 150 B.C. and 350 ± 140 B.C.

5.3.1 Indices and Indicators

AM3 shows a pattern of decline in the trophic index (Fig. 5.2). From the core peak of 471 the index ends the zone at 447, despite the continually strong contribution from eutrophic taxa. This decline is accounted for by the rise in the contribution of *C. bodanica var. affins* (9% T.D.A. at 375cm). As was discussed in section 5.2.2 the trophic requirements of this species are far from certain (Bradbury, 1997). However it has been included as an oligotrophic species in the index as recommended by van Dam (1994). This decline in the trophic index is also mirrored in the pH index as far as a depth of 375cm, again a result of *C. bodanica*. Between the beginning of the zone and this depth the pH index falls from 82 to 57, which is the lowest the index has fallen thus far in the core and is the second lowest point of the whole core. From this low the pH index rapidly recovers and reaches 72 by the end of the zone. Were *C. bodanica* removed from the calculations, the indices would look somewhat different as demonstrated in Figure 5.9.

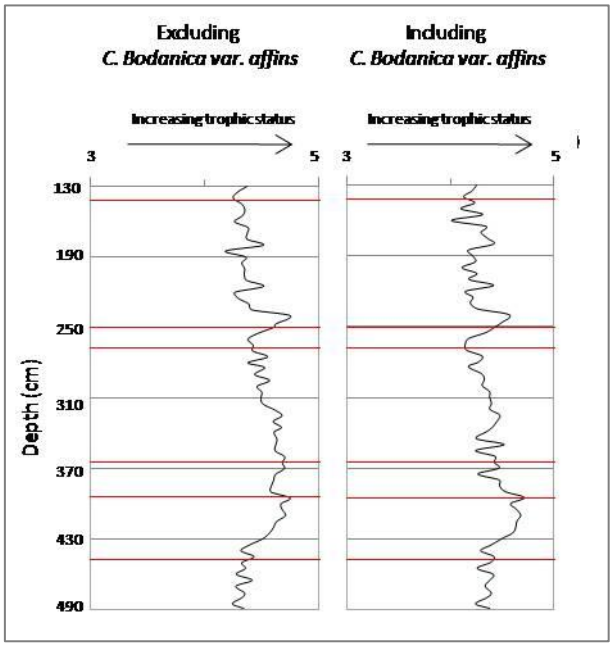

Figure 5.9 The influence on the trophic index when *C. bodanica var. affins* is included and excluded.

The planktonic/periphytic ratio (see Fig. 5.3) continues to show domination by planktonic species with a slight decrease at the beginning of the zone. This is reflected in a ratio of 72:28% at 390cm. However this is short lived with the ratio recovering to ≥ 80:20% by the end of the zone. The preservation of diatoms through this zone continues to stay low through the beginning of the zone, with a fracturing peak of 67% at 380cm. Following this there is a trend towards increased preservation at 46% T.D.A. These data suggest that water levels in Aqualate Mere remained high through AM3, but that there was a decrease in the energy of the environment towards the end of AM3. The salinity index (Fig. 5.4) shows a slightly increasing salinity through AM2 as it rises from the core low of 200 to 218 at the end of the zone. This could suggest a decreasing precipitation, and a slight increase in-wash from the catchment.

5.3.2 Planktonic Species

The planktonic contribution to the T.D.A. does not vary significantly throughout the zone. A significant milestone is reached in AM3 however as the planktonic contribution (see Fig. 5.3) reaches a core peak of 70% at 365cm. This represents a rise of 12% across the length of the zone. There are however significant changes in the diatom assemblage that makes up this planktonic contribution.

As in the previous two zones *C. dubius* is once again dominant, however the species undergoes a sustained period of decline. Beginning at 50% T.D.A. it then sharply declines, ending the zone at only 37% T.D.A. This is marked by significant growth in other species. *C. radiosa*, which is a large, late-summer blooming, meso-eutrophic favouring species (Rioual *et al*., 2007; Hausmann *et al*., 2002), begins the zone representing 7% of the T.D.A. Following this it almost doubles its presence in the assemblage to 13% T.D.A. A similar story is evident in *S. rotula*, which increases from 3% to 8% T.D.A. across the zone. Like *C. radiosa S. rotula* is also a large species that avoids summer blooms, favouring late winter and early spring (Krivtsov *et al*., 2003). *C. bodanica var. affins* also follows a similar pattern; beginning the zone absent from the record before climbing to contribute 8% T.D.A. and then declining slightly to end the zone at 7% T.D.A. Alongside this shift to different species of diatoms is the

continuing decline of *C. costatilimbus*, which ends the zone representing only 4% T.D.A.

The remaining contributors to the planktonic community are *A. islandica* and *A. formosa*. Both of these species are minor contributors to the plankton with *A. islandica* generally only contributing between 3% and 5% of T.D.A. there is however a brief peak of 8% T.D.A. in this species at 380cm. *A. formosa* however is steadily minor contributor at ca. 1% T.D.A.

5.3.3 Tychoplanktonic Species

The contribution through AM3 is erratic; ranging from 26% to 12% T.D.A across the zone (see Fig 5.3). The average contribution lies around 19% T.D.A and there is a significant shift in the tychoplankton. In previous zones *F. construens* had been dominant by a considerable margin, however in AM3 *A. italica* begins to rival *F. construens*. Alongside this change is the disappearance of *C. ocellata*, *F. capucina* and *G. grovei* from the stratigraphic record.

The record of the tychoplanktonic diatoms in AM3 shows a pattern of peaks and troughs, which is consistent with their fluctuating contribution. *F. construens* is a perfect example; its presence in the record is highly unstable at 5% to 14% T.D.A. in a series of peaks and troughs, which span the length of the zone. This pattern is repeated in *A. italica*, which starts the zone at 10% T.D.A and immediately falls to a level of 6% T.D.A. only to peak again at 10% T.D.A at 380cm. This pattern of peaks and troughs is also replicated, to a lesser extent, in the behaviour of *F. brevistriata*.

5.3.4 Periphytic Species

The contribution of periphytic species is relatively stable throughout the zone ranging from between 15% T.D.A. to 23% T.D.A.

The abundance of the majority of the periphytic species is stable throughout AM3 and there are few events of note save the decline in *C. placentula*. Despite this decline,

from 11% T.D.A., to 4% T.D.A., *C. placentula* continues to be the dominant species. Minor peaks in a number of other species such as *N. cryptonella* and *G. accuminatum* are noted within the zone however these are very weak with none representing a contribution of >3% T.D.A. The general picture for periphytic species in this zone is one of significant inactivity.

5.3.5 Correlations

Once again the findings of the diatoms indicate a broadly alkaline and meso-eutrophic lake. This is supported by the L.O.I., rises across the zone from 52% to 59% (see Fig. 5.7). The rise in L.O.I. in here would appear to suggest an increasing autochthonous contribution to the sediments. L.O.I. is a measure of the carbon lost on ignition of a sample and as this rises it indicates increasing carbon content. Conversely decreases in L.O.I. are indications of increasing allochthonous contributions to sediments associated with in-washing of minerogenic sediment from the catchment. However, care should be taken in interpreting L.O.I. in this manner as increasing L.O.I. could also be a result of decreasing minerogenic input, unrelated to autochthonous production in the lake.

Given the indications of meso-eutrophic conditions from diatoms and the dominant lithology of dark grey organic gyttja, rising carbon content, here, would seem to indicate increasing biological production in the lake and hence autochthonous production. Additionally the lake appears to have been dominated by planktonic diatoms once more indicating a relatively high water level. Evidence from the salinity (Fig. 5.4) index suggests that salinity is increasing, perhaps indicating a decline in freshwater input directly from precipitation.

Correlations between the records once again indicate some level of communication. The diatoms *C. radiosa*, *C. bodanica var. affins* and to a lesser extent *S. rotula* begin a period of substantial expansion at the expense of *C. dubius*. This expansion is closely followed, but with a slight lag period, by *Anabaena* in the pollen record. A possible explanation for these associations could be that *Anabaena* is dominating the summer bloom in the lake. *C. radiosa*, which is a later summer to autumnal blooming species

(Rioual *et al*., 2007) and *S. rotula* a winter and early spring bloomer (Kristov *et al*., 2003) would therefore be favoured. An alternate explanation may be that the toxins released by *Anabaena* have a deleterious effect on fish species in the lake. This in turn may have affected the trophic chain in the lake, leading to favourable predation of smaller diatoms, such as *C. dubius* over larger *C. radiosa*, *C. bodanica var. affins* and *S. rotula*. It should also be noted that these changes also occur alongside expansions in cereal pollen. This coupled with minor peaks in HIRM and χlf suggests possible minor catchment erosion in this period (see Fig. 5.6).

A second correlation of interest in AM3 is that of *S. rotula* and the magnetic ratio of χarm/SIRM. This correlation is unusual as work by Oldfield *et al.* (1999) suggested that a ratio exceeding 2.000 kA m^{-1} could be used to identify the presence of bacterial magnetosomes. The ratio surpasses this number twice in AM3 at 390cm (2.500 kA m^{-1}) and at 375cm (2.750 kA m^{-1}) suggesting the presence of bacterial magnetosomes and a link with *S. rotula*. The overall pattern however is one of independence of diatoms from Lake Catchment processes. The only links between the data of Pittam (2006) and diatoms are concerned with process intrinsic to the lake.

5.4 Zone AM4 365cm – 268cm

The period represented by Zone AM4 spans the extrapolated dates ca. 350±140 B.C. to 220±90 A.D. This zone therefore encompasses a vast period of history. This likely ranges from the middle to late Iron Age the zone then covers the Roman conquest of Britain and their subsequent establishment in the landscape.

5.4.1 Indices and Indicators

AM4 shows a general period of decline in the trophic index (Fig. 5.2), with fluctuations throughout the zone. These fluctuations are accounted for by the influence of *C. bodanica var. affins*, as discussed in Section 5.3.1. The index suggests a shift towards a more mesotrophic water body, which is supported by the growth in mesotrophic and meso-eutrophic taxa at the expense of eutrophic taxa. The pH index (Fig. 5.1) displays a different story through AM4. A distinct pattern of increasing alkalinity emerges

towards the middle of the zone, which is followed by recovery. The pH index begins the zone 72 and rises to a peak of 107 at a depth of 325cm. From this point the index indicates a period of acidification and falls towards the end of the zone to a minimum of 54 at the end of the zone.

The planktonic/periphytic ratio (see Fig. 5.3) initially shows an increasing input from plankton reflected in the core peak of 86:14% at 355cm. From this point the general pattern is one of a saw-toothed pattern of declining planktonic contribution. Alongside this is an increasing contribution from mesohalobous (salt tolerant) species and increase in the salinity index, which peaks at 315cm ca. 60±115 B.C. This would appear to indicate slight declines in water levels and a concentration of salts within the lake. A possible explanation could be one of ameliorating climate and decreased precipitation around this time as noted by Lamb (1995).

Species preservation shows a general pattern of increasing preservation. This sees the percentage of fractured valves falling from 45% to 35% T.D.A. at the beginning and end of the zone respectively. However, this occurs by way of peaks and troughs and a particularly intense period of shattering ca. 335cm and 350cm. The general pattern however, indicates a movement towards a lower energy environment. This supports the idea that climate may be ameliorating and windiness decreasing.

5.4.2 Planktonic Species

As has been established there is a general decline in the contribution from planktonic species throughout this zone. Starting at 70% T.D.A. the planktonic contribution falls across the zone to a zonal low of 34% T.D.A. at 280cm before recovering slightly to end the zone at 44% T.D.A (see Fig. 5.3). Although the general pattern is one of decline there is a sharp peak in planktonic species at 275cm where they account for 61% T.D.A.

The pattern of decline in *C. dubius* continues through AM4, however, the species remains the dominant plankton. Starting at a contribution of 37% T.D.A. *C. dubius* declines to contribute only 17% T.D.A. at the end of the zone. This pattern of decline is

not mirrored in any other plankton, which all exhibit different patterns of growth and decline.

After *C. dubius* the second biggest contributors to the planktonic community are *C. radiosa, C. bodanica var. affins* and *S. rotula*. Two of the three *C. radiosa* and *C. bodanica var. affins* exhibit patterns of declining contribution. From a maximum contribution of 13% T.D.A. at the beginning of the zone *C. radiosa* declines to a low of 4% T.D.A. at 300cm. Following this nadir it recovers, reaching 12% T.D.A. at 275cm before declining towards the end of AM4. A similar pattern is exhibited by *C. bodanica var. affins*. *S. rotula* exhibits a very different trend. Starting, representing 8% T.D.A. it almost doubles its contribution to 15% T.D.A. at 325cm. From this point it maintains a steady contribution until 315cm before beginning a pattern of decline ending AM4 at 6% T.D.A.

The remaining planktonic species include *A. islandica*, *A. formosa* and *C. costatilimbus*. In the most part none of these species is particularly dominant within the assemblage, never contributing >10% T.D.A. The only exception is at 275cm where *A. islandica* peaks at 10% T.D.A., which is the culmination of an erratic pattern of blooming and retreat. The peak at 275cm is also concurrent with peaks in *C. radiosa, C. dubius* and that of *A. formosa* at 3% T.D.A. The species *C. costatilimbus* is also at low abundance throughout the zone and it continues the pattern of decline it has been experiencing since its peak in AM1 by way of a minor peak of 5% T.D.A. at 325cm.

5.4.3 Tychoplanktonic Species

Tychoplankton show a pattern of increase through AM4. Beginning the zone at 18% T.D.A., their contribution does not rise significantly until 320cm where it reaches 31% T.D.A (see Fig. 5.3). From this point the contribution fluctuates, but it generally continues to grow until a peak of 43% of the T.D.A. is reached at 280cm. From this point however the contribution immediately crashes to 16% T.D.A.; the lowest point in the zone.

Once again the dominant tychoplankton in the assemblage is *F. construens*, which shows sustained growth (see Fig. 5.8). The species begins at 5% T.D.A. and its contribution does not fall below this level again in the zone. The pattern of growth is erratic via a series of blooms followed by crashes, with each bloom being more intense than the preceding. The most severe of this bloom-crash cycles occurs between 280cm and 275cm where it peaks at 37% T.D.A. before collapsing to 10% T.D.A. *F. brevistriata* also exhibits this general pattern of growth throughout the zone. The species begins at 3% T.D.A. and ends the zone contributing more than double the assemblage at 8% T.D.A. This expansion in *F. brevistriata* is by way of significant peak of 14% T.D.A. at 315cm, which is also the period in which there is a sustained peak of *S. rotula*.

Possible evidence for a high energy environment at the beginning of AM4 is present within the tychoplanktonic community. *A. italica*, as previously mentioned requires turbulence to maintain its buoyancy (Bradbury, 1975) is present between 355cm and 340cm (ca. 300±140 to 200±130 B.C.) at 8-9% T.D.A. This sustained spike is concurrent with peaks in shattered valves of 55% T.D.A. at 340cm, indicative of a high energy environment. From this sustained peak the species declines to 1% T.D.A. and goes through a series of bloom-crash cycles peaking at 8% T.D.A. at 290cm, once again concurrent with an increase in shattered valves.

The contribution from the remaining tychoplanktonic species appears insignificant throughout AM4. There is, however, a small peak of 2% T.D.A. in *C. ocellata*, which is otherwise absent in the zone, at a depth of 330cm. This is significant as in AM1 and AM2 a peak in *C. ocellata* was associated with peaks in magnetics data, indicative of periods of erosion.

5.4.4 Periphytic Species

Periphytic species make a limited contribution to the T.D.A., generally <25% (see Fig. 5.3). There is, however, a slight increase in their overall contribution through the zone with the lowest contribution of 11% T.D.A. recorded at the beginning of the zone. *C. placentula* once again is the most dominant periphytic species contributing between

3% and 6% T.D.A. Of the other periphytic species *N. cincta*, *G. accuminatum*, *N. atomus*, *N. cryptonella* and *E. argus* show patterns of growth. The contribution of each of these species to the T.D.A. generally increases through the zone. Of particular interest is the sustained growth and presence of the species *N. atomus*, *N. cryptonella* and *E. argus* through 320cm to the end of the zone at 268cm.

5.4.5 Correlations

For the fourth successive zone the lithology of the sediments remains constant with L.O.I. reaching its highest levels in the core for the majority of the zone ca. ≥ 55% (see Fig. 5.7). This value however begins to fluctuate at 290cm where it falls to a low of 50% and begins a general pattern of decline. The decline is, however, punctuated by a peak of 56% at 280cm before continuing a linear decline to a low of 46% at the end of AM4. This pattern of stability and high autochthonous production at the beginning of the zone differs to the indications from the trophic index. The index indicates a sharp decline trophic status in the lake at this period of high L.O.I. However as was mentioned in Section 5.3.1 this may be a result of the uncertainty surrounding the autecology of *C. bodanica var. affins*.

The pH index (Fig. 5.1) would appear to support the argument that a high trophic status was reached mid AM4. There is a conspicuous move towards more alkaline water between 360cm and 310cm (ca. 325±135 B.C and 30±110 B.C.), which spans the period of peak organic contribution to the sediments ca. 56-57%. This supports the idea that the trophic status remained or was increasing around this period as higher pH has been associated with high nutrient levels (Johnson, 2003; Smol, 2002). The apparent, diatom inferred, decrease in trophic status could be due to competition between diatoms and *Anabaena*, which reaches extremely high number in AM4. In the peak summer months *Anabaena* may have outcompeted more eutrophic favouring diatoms. This could result in a diluted eutrophic signal as eutrophic species are unable to compete in the summer months.

Further correlations are noted between events in the pollen and magnetics record and the diatom stratigraphy. One such correlation is the period of apparent agricultural

intensification at ca. 340cm and high trophic status and pH. A second is the gradual opening up of the landscape. Alongside decreasing arboreal and increasing herb and grass pollen the planktonic contribution begins a slow decline. This is likely to be a signal of ameliorating climate following the downturn of ca. 850 B.C. However it is possible that the two signals are both independent records of the same forcing, rather than changes in climate forcing human behaviour, which in turn lead to effects upon lake ecology.

A further very interesting correlation noted is that of the ratio of χarm/SIRM and the growth pattern of *S. rotula*. This ratio reaches 3.00 kA m^{-1} at 340cm; surpassing the 2.50kA m^{-1} value which Oldfield *et al.* (1999) used as an indicator of bacterial magnetosomes. After this depth the ratio generally remains above 2.50kA m^{-1} until 290cm. It should also be noted that this spans the period of apparently high autochthonous production discussed at the beginning of this section. The cause of this congruence is uncertain; however it seems clear that the conditions favouring bacterial magnetosomes also favour *S. rotula*.

Other events of note are minor peaks in the $SIRM_{minero}$ of ca. 1.5 x $10^{-3}Am^2kg^{-1}$ and 1.25 x $10^{-3}Am^2kg^{-1}$ at the respective depths of ca. 335cm and 320cm. These appear to be associated with minor peaks in *C. ocellata* and *C. costatilimbus*. *C. ocellata* follows the $SIRM_{minero}$ peak of 1.5 x $10^{-3}Am^2kg^{-1}$ at 335cm, reaching 3% T.D.A. at 330cm. This is of significance as it follows a period of near absence from the record since AM2. The peak in *C. costatilimbus* of 4-5% T.D.A. occurs between 320cm and 325cm, preceding the second weaker peak in $SIRM_{minero}$.

In summary the data from AM4 appear to suggest links between some events in the lake catchment. Examples include catchment erosion ca. 335cm to 320cm. However the overall picture appears to show negligible communication between lake ecology and human based catchment processes.

5.5 AM5 268cm – 251cm

The period represented by Zone AM5 spans the extrapolated dates ca. 220±90 A.D. to 325±80 A.D. This zone therefore likely dates to the zenith of the Roman Empire in Britain and lies within a period where substantial human presence is known within the vicinity of the Aqualate Mere catchment.

5.5.1 Indices and Indicators

The trophic index (Fig. 5.2) indicates that the lake was becoming more nutrient rich with the index climbing from 414 to 443 across the zone. There are also indications of possibly increases in humic matter in the waters as dystrophic species reach 8% T.D.A. by the end of the zone. The pH index (Fig. 5.1) also shows a similar pattern with a trend towards the waters becoming more alkaline through AM5 with the index increasing from 54 to 83 across the zone.

The trend towards a reduction of the planktonic/periphytic ratio established in AM4 continues through AM5. Beginning at 65:35% the planktonic contribution continues to fall with periphytic species dominating the assemblage at 255cm reflected in the ratio 49:51%. This is the first time in over 1000 years that periphytic species have dominated the assemblage. Alongside this increasing periphytic input is a general decrease in preservation (36% to 45%) and relative stability in the salinity index (see Fig. 5.4).

5.5.2 Planktonic Species

C. dubius is once again the dominant planktonic species. The trend of decline observed in the past zone continues into the middle of AM5. The species declines from 22% T.D.A. at the beginning of AM5 to only 15% T.D.A. at 260cm. The apparent terminal decline of the species is arrested at this point and it stages a recovery to finish the zone at 24% T.D.A (see Fig. 5.8).

The general pattern for other plankton is one of decline, which is observed in the species *C. bodanica var. affins* (6% to 1% T.D.A.), *S. rotula* (6% to 4% T.D.A.) and *A. islandica* (4% to 2% T.D.A.). Of the remaining species *C. radiosa* maintains a stable 7% to 8% T.D.A. and *C. costatilimbus* exhibits a period of slight growth from absence at the beginning of the zone to 5% T.D.A. at the end (see Fig. 5.8).

5.5.3 Tychoplanktonic Species

The general pattern for AM5 is of varying contributions from the tychoplanktonic community regulated by the variation in the abundance of *F. construens*. This species experiences a couple of peaks and troughs, beginning the zone at 19% T.D.A. and ending at 25% T.D.A. with a peak of 26% T.D.A. and a low of 15% T.D.A. The pattern for the remaining diatoms, with the exception of *C. ocellata*, is one of decline from peaks at or near the beginning of the zone (see Fig. 5.8).

C. ocellata begins AM5 absent, which is followed by its first appearance at a depth of 260cm before climbing in concentration to 3% T.D.A. by the end of the zone. This is of significance as in previous zones the species has been associated with shifts in the pollen record and alterations in the magnetic signature of the lake sediments.

5.5.4 Periphytic Species

There is a general increase in the contribution of periphytic species throughout AM5; rising from 32% T.D.A. to 38% T.D.A (Fig. 5.3). Once again *C. placentula* is dominant and sustains a contribution of 4% to 6% T.D.A. across the zone. Of the remaining periphytic species there are some patterns of growth such as in the species *N. cincta*, a strong dystrophic indicator, (Denys, 1991). The contribution of this species grows from 2% T.D.A. to 7% T.D.A. across the zone. A different trend is observed in *N. atomus*, which maintains a steady contribution of 2% T.D.A (see Fig. 5.8).

An event of interest in AM5 takes place at the beginning of the zone. At a depth of 260cm (ca. 270 A.D.) there are peaks in a number of species. These species are *G. accuminatum* (4% T.D.A.), *N. cryptonella* (3% T.D.A.), *N. simplex* (3% T.D.A.) and *N.*

detenta (1% T.D.A.). Following this peak these species then begin to decline or disappear from the assemblage by the end of AM5.

5.5.5 Correlations

Data from the trophic and pH index (Figs. 5.1 & 5.2) indicate a general increase in trophic status through AM5. However, this runs contrary to the L.O.I., which indicates decreasing organic production, falling from 46% to 40% (Fig. 5.7). This is likely a result of increased minerogenic input to the lake sediments, suggested by a rises in HIRM and $SIRM_{minero}$. The plankton/periphytic ratio (see Fig. 5.3) shows an increase in periphytic species, which is further evidence for increasing sediment delivery. Increased sedimentation would either decrease lake levels via infilling, or disrupt water column stability, accounting for the shift in the ratio.

The pollen data indicate the zone to be a period of high human impact with agriculture firmly entrenched at 6-7% T.L.P (see Fig. 5.5). Alongside intensive agriculture is the continual depletion of the oak woodlands of the catchment. Such activities would likely promote the landscape instability identified in the magnetics data mentioned above. These activities draw a particularly interesting response from the diatom *C. ocellata*; this species, with a slight lag, mirrors the growth curve of HIRM. *C. ocellata* is a tychoplankton, which originates in benthic habitats, but is generally absent through the core until this point. This suggests that landscape alterations and probable erosive input to the lake are causing uncertainty in the lake ecology. *C. ocellata* appears to be well placed to exploit this uncertainty through the ability to occupy two habitats. The response of this diatom and the planktonic/periphytic ratio in general suggest that the intensification of anthropogenic activities is directly influencing diatoms, and hence, lake ecology in AM5.

5.6 AM6 251cm – 130cm

Since this investigation was unable to viably count diatoms above a depth of 130cm the 12cm of the core from this depth, to the end of AM6 have been added to AM6. The time slice represented by this zone runs from the extrapolated dates ca. 325±80

A.D. to 1640±10 A.D. This represents the longest zone in the core encompassing a number of period's history. These are likely to include the end of the Roman period and the following migration period through to documented history.

5.6.1 Indices and Indicators

The period represented by AM6 is a period of massive change in the preserved diatom assemblage, which occurs alongside significant shifts in the magnetic signatures of the lake sediment and the preserved pollen.

The trophic index (Fig. 5.2) indicates a major perturbation within the diatom record in AM6. Beginning the zone on an upward trend at 443 the index continues to rise until it peaks at 457 at 240cm (ca. 415±80 A.D.). From this point the index registers a sharp fall to 415 at a depth of 220cm (ca. 640±65 A.D.).Following this minima at 220cm the trophic index sharply peaks at 441 at 215cm before falling once more to a minimum of 411 at 200cm. These fluctuations are associated with an increase in eutrophic-dystrophic and mesotrophic taxa. The increase in dystrophic taxa could indicate an increasing turbidity associated with significant increases is suspended solid organic matter.

Following the minima at 200cm the trophic index once again begins to climb to reach 442 at 180cm from which point it stabilises until 165cm. From this point the index generally declines, reaching the lowest point in the core of 401 indicating a significant shift in the trophic state of the lake. The results of the pH index (see Fig. 5.1) indicate a period of remarkable stability in the core. From the beginning of the zone to the end of the core the pH index is generally constrained between values of 76 and 83. There is however, a large increase in alkalibiontic species between 215cm and 200cm (ca. 700±60 to 860±55 A.D.), peaking at 17% T.D.A. at 205cm (ca. 800±55 A.D.).

Alongside the major shifts that occur in the trophic index is a massive shift in the planktonic/periphytic ratio (see Fig. 5.3). The ratio begins the zone at a value of 62:38% and sharply rises to 79:21% at 240cm. From this depth there is then a major shift towards periphytic species reflected in the ratio 12:88% at 230cm. This at first

appears to indicate a major expansion in periphytic species; however, the expansion is modest, 25% T.D.A. at the beginning of the zone to 45% T.D.A. The shift is predominately a result of an increase in the tychoplanktonic contribution, which rises to 45% T.D.A., coupled with a collapse in planktonic species, which reach their lowest core contribution at 6% T.D.A (see Fig 5.3).

This collapse in planktonic species represents a major change in the history of Aqualate Mere; and signals the end of Aqualate Mere's period of relative depth. Following this shift, at ca. 470±75 A.D., the ratio of plankton/periphytic species continue to be dominated by periphyton. The only exception to this is a small excursion at 180cm (ca. 1080±40 A.D.), where the ratio shifts 60:40%. Alongside the changes in the plankton/periphytic ratio the salinity index (Fig. 5.4) also appears to indicate reduction in lake levels. Across AM6 the salinity index shows a general pattern of increase. This pattern is punctuated by two pronounced peaks at 230cm to 220cm and at 190cm when mesohalobous species expand significantly.

The preservation of diatoms (See Fig. 5.7) through AM6 goes through two distinct phases. The first of these phases is a period of increased preservation. Running from the beginning of the zone to the depth of 230cm it coincides with the shift in planktonic/periphytic ratio (Fig. 5.3) and sees the preservation a point where only 11% of the valves are shattered. Following this increase in preservation is a move towards decreased preservation of 43% at 225cm. From this point preservation again decreases reaching a peak of 59% T.D.A. at 205cm, coinciding with a core peak in periphytic and alkalibiontic species. It could be that this shift to decreased preservation is a result of unfavourable water chemistry for preservation leading to increased dissolution of the valves. From this low level of preservation at 205cm the preservation of diatoms generally increases towards the end of the zone ending the zone at 43%.

5.6.2 Planktonic Species

As evidenced in the planktonic/periphytic ratio a major perturbation occurs at 230cm where the contribution of planktonic species falls to a core minimum of 6% T.D.A (Fig.

5.3). This massive decrease is more significant as it occurs only 10cm after a zonal peak in the planktonic contribution of 64% T.D.A.

Reference to Figure 5.8 shows that as in previous zones *C. dubius* continues to dominate. At the beginning of the zone it is continuing a recovery begun in the previous zone. This takes the form of a sharp rise in the contribution from 15% to 40% T.D.A from 247cm to 245cm. Following this peak the contribution immediately collapses to 3% T.D.A. at 230cm, which dates to ca. 530±70 A.D. just after the end of Roman Britain. The contribution from *C. dubius* immediately begins to recover from this nadir; however, the recovery is slow. It is not until a depth of 190cm that the contribution has once again risen above 10% T.D.A. before accelerating to 36% T.D.A. at 180cm. This peak in the species is short lived and represents the beginning of the decline of the species throughout the core.

Alongside the double peaks and troughs in *C. dubius* are a series of minor peaks and troughs in other contributors to the planktonic community. Before this pattern becomes established there is an intense peak in *C. radiosa* at the beginning of AM6. At 247cm the species surges to a contribution of 23% T.D.A., an immediate precursor to the intense peak in *C. dubius*. Following this peak the species rapidly declines to reach a low of 2% T.D.A., concurrent with the minima in *C. dubius*.

The general pattern from this point forth is for minor, but broad peaks, spanning the lows in *C. dubius*. The first phase of these broad peaks occurs in the following species between the following depths: *C. radiosa* between 225cm to 200cm (8% - 9% T.D.A.), *S. rotula* between 225cm to 190cm (2% - 3% T.D.A) and *C. bodanica var. affins* 210cm to 190cm (1% - 3% T.D.A.). Alongside these broad peaks are a series of peaks and troughs in the species *A. islandica* ranging in intensity from 3% to 5% T.D.A.

A second span of peaks follows the peak of *C. dubius* at 180cm. From depths of between 175cm and 145cm there is a broad peak in *C. radiosa* and *A. islandica*, which reach respective contributions of 10% and 8% T.D.A. Alongside these peaks are two minor peaks in C*. bodanica var. affins* at depths of 160cm and 150cm with respective

contributions of 5% and 1% T.D.A. No further peaks are seen in the species *S. rotula* as it disappears from the record.

5.6.3 Tychoplanktonic Species

Tychoplankton undergo a significant expansion close to the beginning of AM6 where they reach 45% T.D.A. at 230cm. From this point the contribution declines to 19% T.D.A. at 215cm. Following this tychoplankton recover and are on an upward trend where they dominate the assemblage at 55% by 140cm.

Once again *F. construens* is the dominant species. The species shows a series of broad peaks and troughs between 230cm and 190cm, coinciding with the crash identified in the planktonic species *C. dubius*. These series of peaks range between concentrations of 20% and 34% T.D.A. and troughs of 12% and 16% T.D.A. Following this the species collapses to 8% T.D.A. at a depth of 185cm, which coincides with the peak in *C. dubius*. From this point on the species rapidly increases its contribution to the assemblage; ending the core at 46% T.D.A.

Alongside the growth in the contribution from *F. construens* is the increase in contribution from *F. brevistriata*. The presence of this species through AM6 rises to levels not seen in the core since AM1. The species reaches a peak of 13% T.D.A. early in the zone at a depth of 235cm. From this point *F. brevistriata* maintains a steady contribution of >7% T.D.A. through the zone before rising to 15% T.D.A. at 190cm. From this peak the species slowly begins to decline to end the core at 8% T.D.A.

The most significant change in this zone occurs in *C. ocellata*. This species records a sharp increase, from 3% T.D.A. at the beginning of AM6 to 18% T.D.A. at 230cm. This six-fold increase in the species again coincides with sharp decline identified in *C. dubius*. However, this peak is short lived and C. ocellata has vanished from the assemblage by 210cm. It is likely that the factor forcing the increase in *C. ocellata* is the cause of the collapse in plankton at 230cm. Following this collapse in *C. ocellata* there are a number of smaller peaks, ca. 3% T.D.A, however these are not prolonged.

The remaining tychoplanktonic species within the assemblage, *A. italica* and *F. capucina*, are generally present in low numbers. General patterns of broad peaks are shown in these species which also coincide with the broad peaks previously identified in the planktonic assemblage.

5.6.4 Periphytic Species

Periphytic species dramatically increase at the beginning of AM6 and grow to reach the highest contribution throughout the whole core (see Fig. 5.3). Beginning the zone at 25% T.D.A. they quickly rise to reach 49% T.D.A. at 230cm. From this point the contribution remains ≥30% T.D.A. and continues to grow to 62% T.D.A. at 185cm. Following this peak core concentration the periphytic species become less prominent and end the core representing only 25% T.D.A.

As in all of the previous zones *C. placentula* is once again the dominant species (Fig. 5.8). Beginning the zone representing 3% of the T.D.A. there is a slow rise in the contribution to reach 13% T.D.A. at 220cm. Following this peak there is a slight contraction before an intense peak of 32% T.D.A. at 185cm. This represents the peak core concentration of *C. placentula* and from where it begins to slowly decline in a pattern of peaks and troughs before ending the core at only 4% of the T.D.A.

The general pattern of broad peaks observed, and previously described, in the plankton is observed in a number of the periphytic species. There are broad, and relatively shallow, peaks observed in the species *F. pinnata*, *A. ostreupi* and *D. ellpitica* alongside steeper broad peaks in *N. cryptonella* and *G. accuminatum* between the two intense peaks in *C. dubius*. These all decline to ≤1% T.D.A. Following this decline the species *G. accuminatum*, *N. cryptonella*, and *F. pinnata* emerge to broadly peak once more.

Aside from the patterns of broadly peaking diatoms there are a number of species which exhibit short intense peaks. Two species, in particular, *N. cincta* and *N. atomus* both exhibit sharp peaks in intensity of 9% and 7% T.D.A. at 230cm, coinciding with the peak in *C. ocellata*. These further mirror *C. ocellata,* declining in roughly the same

pattern, suggesting a common forcing mechanism. Analogues for this behaviour of concurrent peaking are present in previous zones, particularly with *N. cincta* in AM1, further supporting this idea of a common mechanism.

A significant event in AM6 is the peak in *N. scutteloides* given the near absence of this species (with the exception of a period in AM1) from the core prior to this event. Starting the zone absent from the assemblage, it first registers a contribution of 1% T.D.A. at 235cm, from which depth its rises steeply to peak at 12% T.D.A. at 205cm. Following this *N. scutteloides* then swiftly disappears from the record by 185cm. Information on the autecology of *N. scutteloides* is limited. Denys (1991) indicates it favours alkalibiontic and eutrophic waters while being a benthic species. Further literatures searches find little or no mention of the species, suggesting it is relatively uncommon.

Alongside the trends described above, AM6 sees significant increases in a number of periphytic species previously present only at 'background' concentrations. Some of these species such as *Cymbella aspera*, *Fragilaria parasitica* and *Cymbella silesiacum* appear as only very minor contributors, while others: *E. argus*, *A. libyca* and *Suriella ovalis* rise to contribute up to 5%, 4% and 5% T.D.A. respectively. This suggests that there is a significant expansion of periphytic habitats in this zone allowing for this observed increase in periphytic diversity.

5.6.5 Correlations

It has been established that AM6 is a period of great change, which encompasses a large time period (almost 1300±110 calendar years). AM6 is also a period of significant change in the pollen and magnetics and close correlation with the diatom record. This suggests that during AM6 the lake and catchment became more closely integrated.

The first, and perhaps most significant, correlation occurs at the beginning of AM6. This is characterised by a major increase in the HIRM and significant decline in *Quercus* (see Figs. 5.5 & 5.6). HIRM rises from 0.200mAm^{2}kg^{-1} at 251cm to 0.600mAm^{2}kg^{-1} at

ca. 235cm closely following the decline in *Quercus* to ca 10% T.L.P. at the same depth. Alongside this is the continuing decline of L.O.I., which reaches minima of 29% at 230cm. The change in HIRM is mirrored in *C. ocellata*, but with a slight delay as it peaks at 230cm. In the other direction is the complete collapse in *C. dubius*, and planktonic species in general, through this period. Clearly the congruence of these changes is more than a coincidence, and suggests major perturbation in the palaeoecology of the lake between ca. 415±80 A.D. and 640±65 A.D. The possible causes for these changes are further discussed in chapter 6.

The second significant correlation is the congruence of growth in *C. dubius* and arboreal pollen, particularly *Quercus* after 230cm. This pattern has been established since the beginning of the core, but is most obvious in AM6. As *Quercus* begins to recover following its low at 235cm so does *C. dubius*, but with a slight lag. This pattern continues with both *Quercus* and *C. dubius* rising to peak contributions in the zone at ca. 180cm, which dates to ca. 1080±40 A.D. at the height of the so called Mediaeval Warm Period (Lamb, 1995).

Other correlations in the zone include the previously established relationships between *C. radiosa* and *C. bodanica var. affins* with *Anabaena*. This pattern once more appears in the broad peaks that span the peak of *C. dubius* at 180cm. The pattern of *S. rotula* following the χarm/SIRM ratio also continues through AM6.

5.7 Chapter Summary

This chapter has sought to first and foremost assess and describe changes in the diatom stratigraphy. Secondly it has attempted to identify links between broad changes in the diatom community and changes in the lake catchment processes, which are taken to reflect human activity. This was undertaken in order to identify if changes in the catchment and lake were integrated responses to external forcing variables, such as climate or were the result of human activity.

The findings of the chapter are inconclusive due to the difficulties in untangling the signals of the forcing variables (Barber *et al*., 1999; Battarbee, 2000: Berglund, 2003).

Despite this a number of things can be said about the responses of diatoms to catchment processes:

1. There is common timing to some of the changes in the catchment and those in the lake.
2. Certain diatom species appear to be mirroring changes in pollen and environmental magnetics. Such as *C. dubius* and tree pollen, *C. radiosa* and *C. bodanica var. affins* with *Anabaena*.
3. Some events in the catchment, such as those in AM6, can be shown to have directly preceded similar changes in the diatom stratigraphy. These can be said to be the direct driving force behind such changes.
4. Evidence for changes in diatoms at times of climatic deterioration is present. However it is unclear if this is mediated through other forcing variables (Anderson, 2000). It is more likely that any records of climatic changes are artefacts of climatic forcing on human populations, which is in agreement with Battarbee (2000).

This chapter has therefore has succeeded in establishing links between some changes in the catchment and changes in the palaeoecology, as reflected by diatoms. However it has had less success in establishing if changes are a result of anthropogenic or climatic forcing. This is something that the next section will address further.

6.0 Discussion

6.0 Introduction

The following chapter will attempt to provide explanations for the events and trends identified in the diatom record. Furthermore the chapter seeks to integrate these findings with those of Pittam (2006) and provide a compelling narrative for the changes observed from Aqualate Mere ca. 1100±200 B.C. to ca. 1650±10 A.D. This will be achieved by the discussion and interpretation of three key periods. These have been established by analysis of the results in the previous chapter and are considered key periods of palaeoecological change over the time represented by the core.

6.0.1 Three Key Periods

Period No.	Depths (cm)	Extrapolated date (2 σ calibrated)	Key Events
1	465 - 425	ca. 950±190 - 710±170 B.C. (Late Bronze Age)	• Major peak in *C. costatilimbus* ca. 920 ±190B.C. • Peaks in HIRM, $SIRM_{minero}$ and χarm concurrent with peak in *C. costatilimbus*. • Decline in arboreal pollen peaking ca. 900±190 B.C. • Expansion in planktonic diatoms from 770±175 B.C. leading to major alteration in planktonic/periphytic ratio.
2	425 -255	ca. 710± B.C. – 300± A.D. (Iron Age – Roman)	• Rise in turbulence indicators *A. italica* and *A. islandica* from ca. 680 ±165B.C. • Appearance of *C. radiosa* (ca. 650±165 B.C.) and *C. bodanica var. affins* (ca. 600±160 B.C.) closely following rise in *Anabaena*. • Three fold rise in cereals from ca. 680 ±165B.C. • Peak in planktonic/periphytic ratio ca. 300 B.C. • Rise in *S. rotula* ca. 680±165B.C. broadly peaking between ca. 120±120 B.C and 60±115 B.C. Concurrent rise in χarm/SIRM ratio. • Rise and dominance of *Anabaena*.
3	255 - 130	ca. 300± A.D. – 1650± A.D. (Late Roman through to documented history)	• Strong peaks in *C. dubius* (ca. 415±75A.D.) and *C. radiosa* (350 ±80A.D.) followed by collapse ca. 530±70 A.D. • Shift in plankton/periphytic ratio ca. 530±70A.D. to periphytic dominance. • Rise of *C. ocellata* from 300±115 A.D. peaking at ca. 530 ±70A.D. • Rise in HIRM concurrent with decline in *Quercus* closely tied to *C. ocellata* rise. • Peaks in *N. Cincta* and *N. Atomus* ca. 530±70 A.D. • Recovery of C. dubius from 530±70 A.D. to peak at ca. 1085±40 A.D.

Table 6.1 The four keys periods in the palaeoenvironmental history of Aqualate Mere.

6.1 Period 1: Late Bronze Age Climate Change?

The time slice for Period 1 (P.1) lies between the depths 465 and 425cm. This has been extrapolated to fall between ca. 950±190 and 710±170 B.C., representing a period in the late Bronze Age. Selection of this period was based upon significant alterations in the diatom stratigraphy and changes in the pollen and magnetics record indicated below in Figure 6.1.

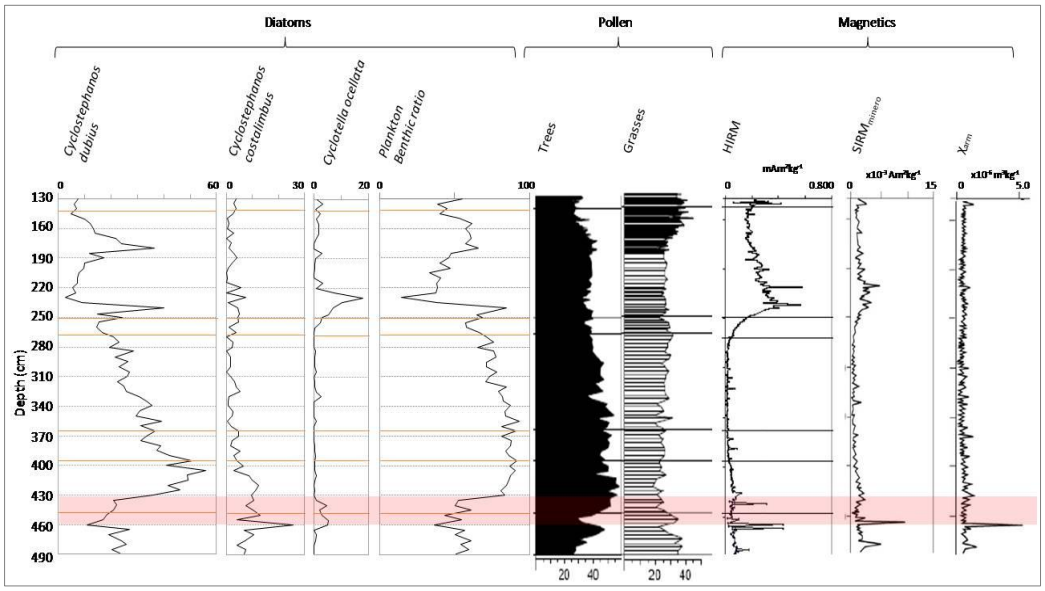

Figure 6.1 Key changes occurring during Period 1 (highlighted in red) in diatoms, pollen and magnetics between depths of 465cm and 425cm (adapted from Pittam, 2006)

P.1 represents a period of transition in both within the Mere and the catchment. Beginning at ca. 950±190 B.C. there is a major shift in the planktonic diatom community attested by a contraction in *C. dubius* (27% to 11% T.D.A.) and concurrent expansions in *C. costatilimbus* (7% to 26% T.D.A.) and *C. ocellata* 0% to (5-6% T.D.A). Associated with the change in the diatoms are peaks in the magnetic variables HIRM, $SIRM_{minero}$ and χARM. Following this cluster of peaks is a period of uncertainty in the diatoms and a shift in the plankton/periphytic ratio. All of these changes are, initially, preceded by a sharp decrease in preserved arboreal pollen, from 48% at ca. 960±190 B.C. to 25% T.L.P. by ca. 900±190 B.C. Clearly there is a major perturbation during this period resulting in a dramatic change in the palaeoecology of the Mere.

One of the potential causes of the changes observed in P.1 is climatic deterioration. As has been discussed in Section 2.3.2 the late Bronze Age was a well documented period of deteriorating climate (Lamb, 1995; van Geel *et al*., 1996; Berglund, 2003; Swindles *et al*., 2007). The changes in this period have been identified by Bond *et al*. (1999; 2001) as a part of a ≈1470 climate cycle linked to changes in ocean circulation patterns. The causal event, namely freshwater input into the North Atlantic, leading to reorganisation of ocean circulation was timed to a date of ca. 850 cal. B.C. (Bond *et al*., 1999; 2001). Other authors have linked the changes to variation in sunspot activity (van Geel *et al*., 1996; Swindles *et al*., 2007). Regardless of the mechanism a climatic downturn (leading to increased wetness and windiness) is widely documented in the late Bronze Age ca. 850 B.C.; a date, which fits neatly into the range established for P.1. Could the changes in diatoms occurring between 950±190 and 710±170 B.C. represent a signal of global climate cycling and climate change? The fact that P.1 spans a period of documented climatic change does not, in its self, suffice as an explanation. To support this hypothesis there must be evidence of a changing climate opposed to evidence for changes resulting from human impact (Barber *et al*., 1999).

6.1.1 Evidence for Climate Change

Human activity is clearly implicated in the near halving of woodland, recorded in the reduction of arboreal pollen from 48% to 25% T.L.P. at the beginning of P.1. This clearance would also appear to be the causal factor behind the changes observed in P.1. Large scale clearance of woodland would likely lead to destabilisation of catchment soils, making them more susceptible to erosion. Erosion and in-wash of soils into the Mere would then account for the signals observed in HIRM, $SIRM_{minero}$ and χARM, and the changes observed in the diatoms. Human activity therefore would seem to be the forcing variable of changes in P.1. However human populations do not live in isolation to climate and a changing climate would almost certainly affect human behaviour. Dark (2006) dated a similar pattern of renewed clearance to the late Bronze Age at a number of sites across Southern England. This, she speculated, was a response of human populations to climate change. As climate deteriorated more woodland was cleared to create more arable land to guard against the increased risk of crop failure. Therefore it may be argued that the observed changes are signals of

one forcing variable (climate) influencing another; in this case human activity. This is something that cannot be easily resolved and serves to highlight the difficulties in untangling anthropogenic and climatic signals (Barber *et al*., 1999; Battarbee, 2000).

Human activity, manifested as woodland clearance and soil erosion, does not explain the changes observed in the diatom assemblage and therefore is only a proximate factor. The ultimate reasons for the peak in *C. costatilimbus*, at the expense of *C. dubius*, and the brief expansion of periphytic and tychoplanktonic species, followed by planktonic expansion remain unresolved. Little is known of the autecology of *C. costatilimbus*. The reasons for its apparent response to sediment in-wash can, therefore, only be speculated upon. However, Bradbury (2000) noted its morphological similarities to another *Cyclostephanos* species and speculated that it favoured high nutrients. Unfortunately this does little to resolve why it should out-compete *C. dubius*. What is important to note is that the ecosystem appears to be in a period of transition. *C. ocellata* and *F. construens*, tychoplanktonic species equally at home in the benthos or plankton, peak immediately after *C. costatilimbus.* These species then maintain a broad presence through to 440cm to 430cm (ca. 800±175 to 740±175 B.C.) at which point *C. dubius* expands and the planktonic/periphytic ratio shifts. This suggests that something other than a brief period of catchment erosion may be forcing the changes in the diatom community. Could this change be a direct signal for climatic change?

Deteriorating climate would provide a compelling explanation for the growth in *C. dubius* and associated shift in the planktonic/periphytic ratio. A climatic downturn would almost certainly lead to increased precipitation and windiness as observed at other locals (Gaillard, 1991; Lamb, 1995). This could explain the observed changes in one of two ways: increased precipitation leading to increased water levels and hence domination by plankton (Wolin & Duthie, 1999). Something potentially supported by the decline in the salinity index suggesting dilution of salts in the Mere. Or more convincingly; increasing windiness and wetness could lead to increased mixing of the lake, re- suspension of nutrients (Anderson, 2000). This would increase turbulence and turbidity thereby limiting the photic zone providing a competitive advantage for planktonic species to dominate. The opening up of the landscape observed in the

pollen diagrams would also act to amplify such a process as the lake became more exposed to wind (McGowan *et al*., 1999).

6.1.2 Anthropogenic or climatic?

The question remains; are the changes observed through P.1 a result of climate or human processes? Given the available data it is likely that the answer lies somewhere between the two. Undoubtedly there was a major climatic event around the end of the Bronze Age, however the manifestation of this impact in the sediment archive of Aqualate Mere remains unclear. It is likely that the sequence of events recorded is, first, of climate forcing human behaviour, potentially followed by a more direct climatic forcing. The probable sequence of events is as follows:

1. Climatic deterioration potentially associated with Bond Event 2. Leading to increasing human impact (Dark, 2006) seen in the contraction in arboreal pollen and the resulting catchment erosion as soils are exposed to increasing precipitation.
2. A sudden in-wash of sediment and probably nutrients. This is characterised by a peak in *C. costatilimbus* along with a disruption of the ecological balance of planktonic and periphytic habitats in the Mere, manifested in the rise of tychoplankton.
3. This clearance erosion sequence however appears to be short lived. It is rapidly followed by a mass expansion in planktonic species. Tied to this is a shift towards higher trophic state as probable higher precipitation and wind driven mixing increases available nutrients. This sequence would represent the increasing climatic impact on the catchment (Anderson, 2000).
4. Increasing precipitation may have also led to a sharp rise in the water table and flooding in a low lying (ca. ≤ 100m A.O.D.) catchment such as Aqualate Mere. This is turn would have put further pressure on agriculture, potentially leading to potential landscape abandonment, suggested by decline in agricultural indicators, cereals and recovery of trees. Such an event has been documented at nearby Crose Mere (Beales, 1980).

The sequence of events described above appears to be the most likely explanation for the changes observed in the proxy record. Therefore there does appear to be evidence of climatic cycling, potentially associated with Bond Event 2, present within the preserved sediments. However as was established in the literature review resolving the direct contribution from climate and those of climate induced human activity is difficult. Therefore it is probable that the signals seen are an ad-mixture of direct climatic influences and human mediated climate influences.

6.2 Period 2: Eutrophication

Following the end of P.1, which was placed at 425cm, P.2 immediately begins dating to ca. 680±170 B.C. The duration of this period is more than four times the length of P.1; spanning the pollen zones AM3 and AM4 along with parts of AM2 and AM5, ending at 255cm, ca. 300±115 A.D.

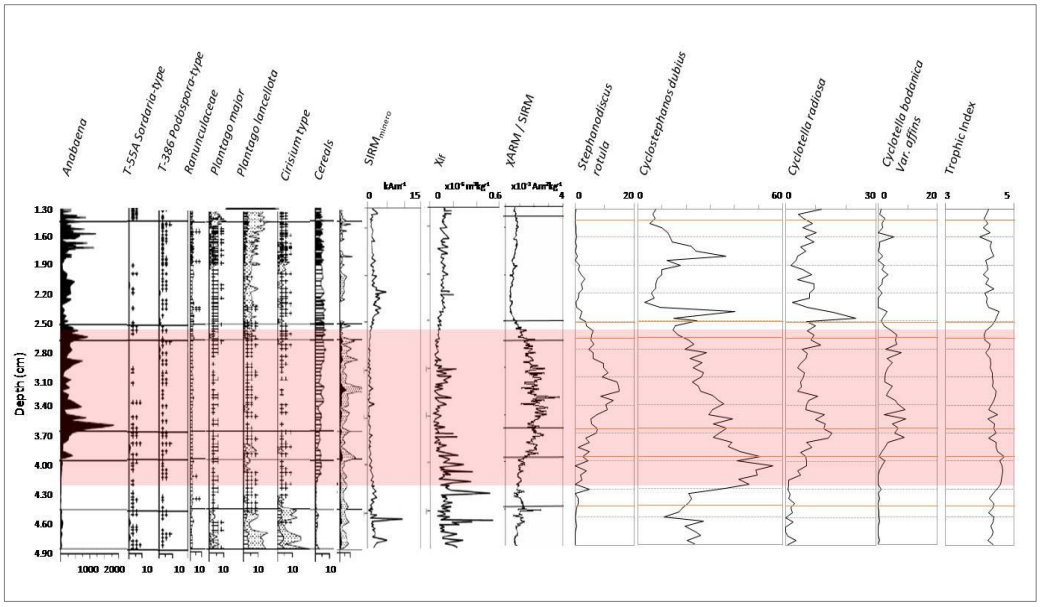

Figure 6.2 The key changes occurring during Event 2 (highlighted in red) in diatoms and pollen between depths of 420cm and 360cm.

P.2 dates from and spans the entirety of the Iron Age, and encompasses the Roman conquest up until ca. 300±115 A.D. This time slice has been selected due to the dominance of planktonic species through the period and the emergence of a number of 'new' species alongside the rise in *Anabaena*. It is hoped that the discussion of this period will move to resolving Objective 3. Figure 6.4 is a timeline of the events through Period2.

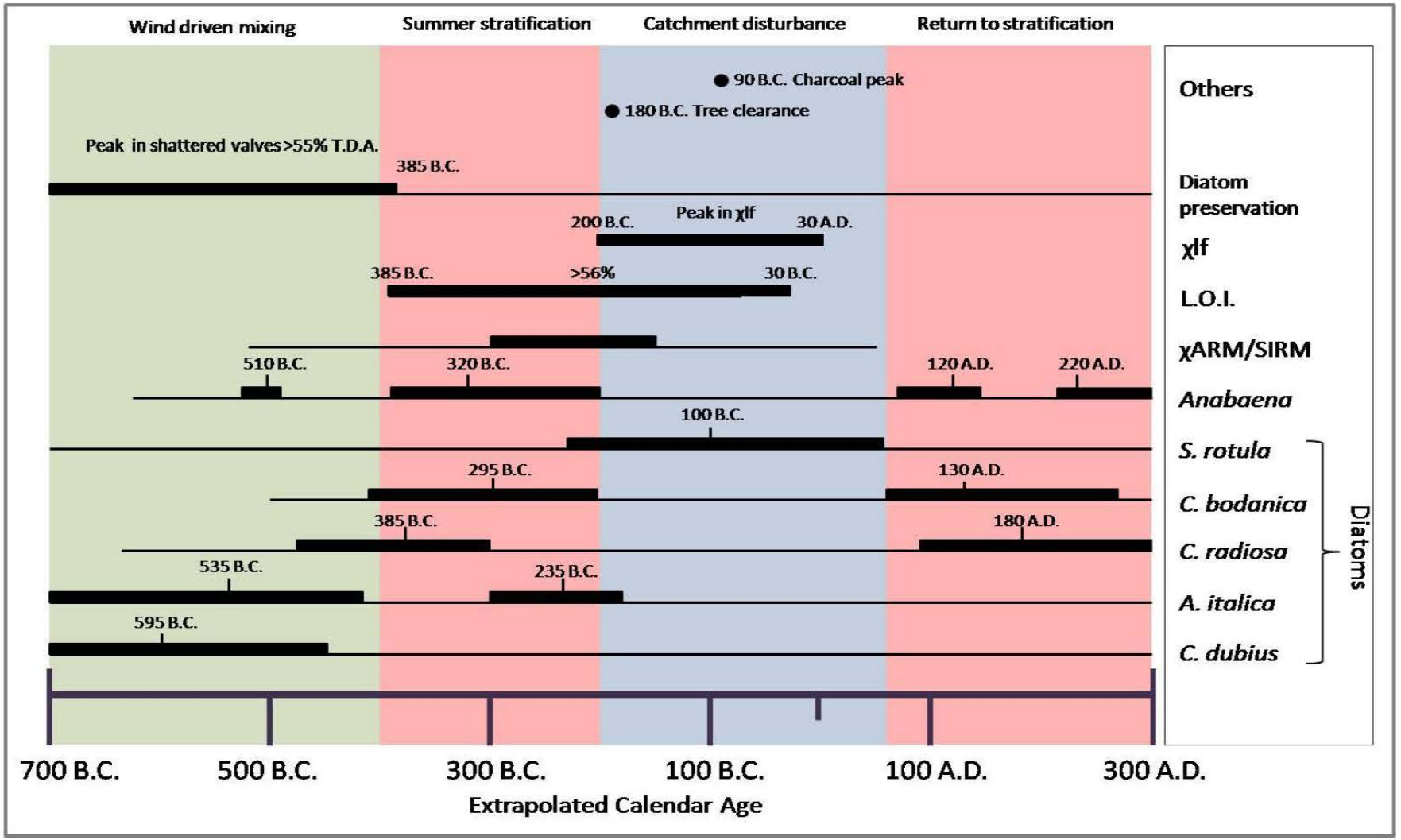

Figure 6.3 Timeline of changes through Period 2. The four key periods are illustrated with broad peaks in diatoms and other proxies and their relative dates indicated.

6.2.1 Wind Driven Mixing

As was described in last section Aqualate Mere switched to a planktonic dominated water body from 770±170 to 740±170 B.C., which was linked with climatic deterioration. The data from P.2 would suggest that this deterioration continued to influence the Mere through the beginning of this period. Strong evidence for continued wind driven mixing is present until at least 400±145 B.C. from a number of lines of evidence.

A major shift towards decreased diatom preservation occurs between 425 and 370cm (ca. 680±170 to 380±145 B.C.), with ≥55% T.D.A. shattered between those depths. This represents a major departure from the mean shattering of 38% T.D.A. and suggests a higher energy environment. The rise of *A. italica* and *A. islandica*, to a lesser extent, provides further evidence. *Aulacoseira* species have been shown to require turbulence to maintain their presence in the water column, suggesting a high energy environment (Bradbury, 1975; Pilskaln & Johnson, 1991; Owen & Crossley, 1992). A final piece of evidence for a windier wetter climate is the rise in *C. dubius*. Windiness would increase mixing and hence turbidity and nutrients are mixed through the lake system (Anderson, 2000). This would favour the growth of *C. dubius*, which is a strong eutrophic indicator (Denys, 1992; van Dam, 1994). Wind driving mixing would therefore explain the rise and sustained peak of *C. dubius* through until 400cm (ca. 445 B.C.).

The beginning of P.2 therefore appears to represent a period of increasing influence from climate on the lake. However there are indications from the pollen and magnetics data that some of these changes could have, if not been forced, helped by human activity. A rise in cereal pollen occurs through this period and is accompanied by a relatively strong χlf signal. This suggests that farming may have returned, leading to destabilisation of catchment soils. This could have lead to in-wash of nutrients to the lake, perhaps not driving, but exacerbating the changes (Foster *et al.*, 2000). However were this a continued period of deteriorating climate it seems counterintuitive that farmers would begin a re-expansion of farming in a climatic

downturn. However it is possible the presence of cereals at this time may represent threshing of cereals in the catchment rather than growth (van Geel, 2003).

6.2.2 Ameliorating Climate

Following the climatic deterioration that began ca. 850±190 B.C. a more stable climatic regime began to emerge ca. 350±140 B.C. (Lamb, 1995; Swindles *et al*., 2007). A switch to a warming more stable climate around this time would explain the changes occurring at Aqualate Mere in the middle of P.2. Throughout the second half of P.2 from ca. 400±145 B.C. to ca. 200±125 B.C. there is evidence from all proxies that Aqualate Mere became highly eutrophic and may additionally have been seasonally stratified. These are conditions that require a relatively calm, warm summers to develop (Smol, 2002). The suggestion of lake stratification here and discussed below is very tentative as Aqualate Mere is relatively shallow and exposed lake. This is something which would work to inhibit lake stratification and make it highly unlikely.

From ca. 450±140 B.C. *C. dubius* and *A. italica* both begin to decline in importance reaching respective lows of 31% T.D.A. and 0% T.D.A. ca. 400±145 B.C. Aligned to this is a shift towards increased diatom preservation. This is important as these species indicate higher energy environments and hence windier more unstable climate and a decline in their importance would suggest an ameliorating climatic regime.

A further line of evidence for a shift towards a more stable, highly eutrophic system is the rise in the χARM/SIRM ratio above 2kAm^{-1} (Pittam, 2006). This ratio reaches its zenith between 300 and 200 B.C and is of significance as it indicates the presence of bacterial magnetite production and hence magnetotactic bacteria (Oldfield, 1999). Magnetotactic bacteria require anaerobic conditions for respiration (Schuler, 1999) and their apparent presence could therefore indicate anoxic conditions, one of the diagnostic features of eutrophic, stratified water (Smol, 2002). This however, is a very tentative suggestion. It is equally possible that only the sediments in which potential bacterial magnetosomes were active was anoxic rather than the lake water.

Concurrent with these changes is the rise of *C. radiosa* and *C. bodanica var. affins*. These species occupy and thrive in ecological niches that can exist in seasonally stratified conditions. Firstly *C. bodanica var. affins* is associated with warm waters (Popovskya, 2007) diagnostic of stratified waters. Second and more importantly the species is known to bloom in the metalimnon, which only develops during summer stratification when phosphorous concentrations are low following spring mixing (Stevens & Dean, 2008). *C. radiosa* is also diagnostic of stratified waters as it blooms during early autumn as summer stratification breaks down and a return to mixing brings a release of nutrients (Rioual, 2007). Stratification could also explain the reduction in *C. dubius* as it is limited to a single blooming period during the spring months and is forced to compete with *C. radiosa* in the autumn period (Bradshaw & Anderson, 2003).

The final piece of evidence is the rise of the cyanobacteria *Anabaena* at ca. 1750% T.L.P through this period (Pittam, 2006). This again provides tentative support for warm, stratified highly eutrophic conditions. Cyanobacteria are diagnostic features of eutrophic water (Reynolds, 1979; Smol, 2002) and are thermophilous (Ralska-Jasiewiczowa & van Geel, 1992). For the numbers identified in the sediments of Aqualate Mere they must have been forming large summer blooms through the period 400±145 to 200±125 B.C. This may provide tentative evidence of stratified calm waters as such blooms would be unable to form in turbulent systems (Reynolds & Walsby, 1975; Reynolds, 1979).

The changes observed from ca. 400±145 to 200±125 B.C. have thus far been explained without reference to catchment processes. This would suggest that climate rather than human activity is the sole forcing variable, however this would seem unlikely. The timing of the above changes does occur in concert with a presence of ca. 5% T.L.P. of cereals and other agricultural indicators (Pittam, 2006); suggesting a strong human presence in the landscape. In fact Pittam (2006) cited the rise in *Sordaria* and *Podospora* type fungi as evidence for increased agriculture and stocking densities of animals (van Geel, 2003a) He went on to propose that increased faeces and subsequent in-wash of nutrients was the driving force behind the rise in *Anabaena* during this period. The diatom data does not support this, but does not rule out a

contribution. It seems more likely that Aqualate Mere, similar to other West Midland meres, following a climatic amelioration, provided the conditions (potential stratification and moderate alkalinity) for such blooms to develop (McGowan *et al*., 1999). This mechanism of phosphorous loading via faeces, may therefore have contributed by feeding other phytoplankton (diatoms etc) earlier in the season. These species would then proceed to deplete the available nitrogen leading to a limitation. This would have allowed *Anabaena* (a nitrogen-fixer) to flourish in summer months (van Geel *et al*., 1994). Once more the influence of climate and human factors is difficult to untangle (Barber *et al*., 1999: Battarbee, 2000).

6.2.3 Catchment Disturbance

Following 200±115 B.C. (ca. 340cm) there is a further change and reorganisation of the diatom community which persists until ca. 60±105 A.D. There are indications from the decline in the χARM/SIRM ratio, *Anabaena, C. radiosa* and *C. bodanica var. affins* that if stratification was possible it became less reliable. *S. rotula* expands and broadly peaks >10% up to 16% T.D.A. during this period, establishing itself as the dominant planktonic species after *C. dubius*. *S. rotula* is a strong eutrophic indicator and blooms in spring and winter mixing (Kristov *et al*., 2003) and the reasons for its rise during this period are unclear. A relatively strong correlation between the species and the χARM/SIRM as discussed in Section 5 is noted, however the significance of this is once again unclear.

What can be said of the period ca. 200±115 B.C to 60±105 A.D. is that there is almost certainly an intensification of land use in the catchment. Cereal pollen continues to rise alongside a period of tree felling in ca. 180±125 B.C (Pittam, 2006). This is accompanied by a slight rise in the χlf through this period suggesting an increase of catchment erosion and sediment influx to the lake and hence turbidity. This is supported by small peaks in *C. ocellata* and *C. costatilimbus*, which had otherwise been in terminal decline. Both species were previously associated with catchment disturbance ca. 900±190 B.C. at 460cm in the core. Additional support comes from the salinity index, which shows an increase and peak around this period, concurrent with a rise in mesohalobous taxa. This could explain the decrease in *Anabaena* around this

time. As a nitrogen fixing bacteria, *Anabaena* requires high light levels to undertake this energy intensive process (van Geel *et al*., 1994). Increased turbidity would provide the mechanism for its decline through this period. Similarly turbidity, limiting light penetration, would explain why the metalimnon inhabiting *C. bodanica var affins* would also suffer.

6.2.4 Declining Human Impact

Following the period of apparent catchment disturbance the influence of human activity on the Mere appears to go through a period of decline. From ca. 60±105 A.D and through to ca. 300±85 A.D. *C. radiosa*, *C. bodanica var. affins* and *Anabaena* all return. This may be possible evidence of stratification as discussed above, but given the lakes shallow nature this is unlikely. The Mere, however, appears to become less productive. There is also a gradual decline in both the trophic index and L.O.I. through this period. Furthermore, although *Anabaena* returns to a high presence, it is nowhere near as high as earlier in the period between 400±145 and 200±125 B.C.

These findings are unusual as this period spans the beginning of the Roman occupation of Britain, when significant impacts on the environment would have been expected. It is stranger still as the catchment is surrounded by numerous Roman forts, camps and villas and only 16km from the *civitas* Viroconium Cornoviorum (Pittam, 2006). Furthermore the pollen record of Pittam (2006) shows a major increase in cereals through this period rising to almost 10% T.L.P. It may be that the algal blooms in this period were self supporting. The Romans may have avoided farming around and exploiting the resources of the Mere seeing it as a 'polluted' body, common to the modern day view of such waters. This would then have resulted in a reduced human impact on the mere. Alternatively it may be that the difficulties of ascribing and extrapolating dates when using radiocarbon dating (McCarthy, 1995) means that the dating of this period is in fact inaccurate. Regardless of the causes for the apparent stability towards the end of P.2 it is also the beginning of the end for Aqualate Mere as plankton dominated, eutrophic body with high autochthonous production. Following ca. 300±85 A.D. the effects of the Roman occupation truly become known, and their presentation in the palaeoecological record is discussed in the next section.

6.3 Period 3: Roman Impacts

Period 3 begins at 255cm dating to ca. 300±85 A.D., and runs to 130cm ca. 1650±10 A.D. This period encompasses the end of pollen zone AM5 and all of AM6, which covers the zenith of the Roman period into the Roman migration period and beyond through to into documented history. This time slice has been selected as there is a major shift in the planktonic/periphytic ratio with a return to periphytic dominance. The cause of this shift can be ascribed to a major perturbation, which occurred in the late Roman to early migration period. However there are questions surrounding the dating of this episode, which are discussed further in this section.

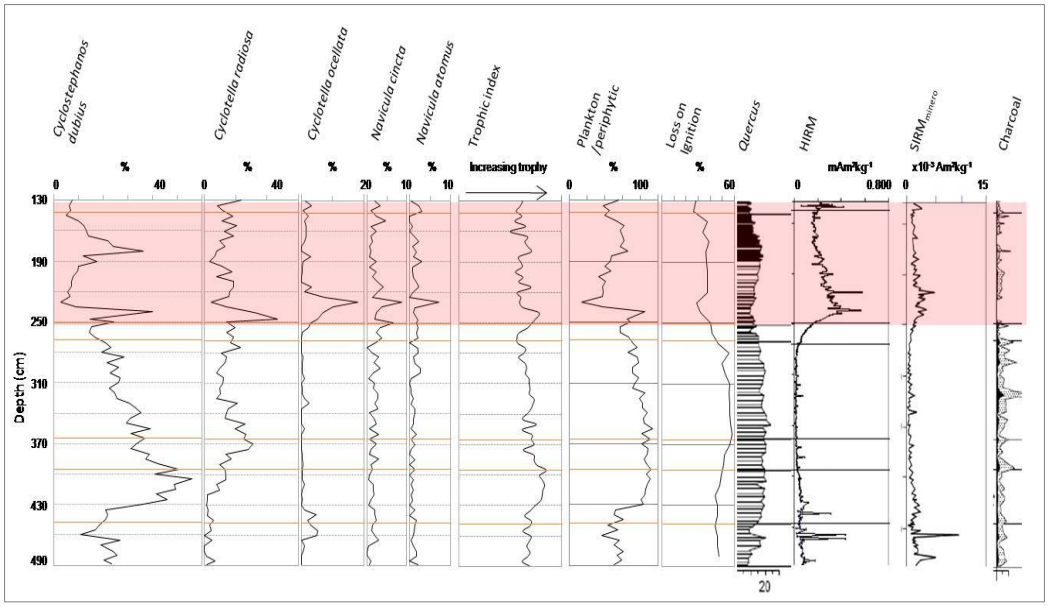

Figure 6.4 The major alterations in diatoms and significant changes in pollen and magnetics data through Period 3.

The diatom record from the end of P.2 indicated evidence for potentially seasonally stratified water dominated by planktonic diatoms and cyanobacterial blooms. This begins to break down at the beginning of P.3, but plankton continue to dominate, and increase their presence in the assemblage. Following ca. 415±80 and up to 530±70 A.D. there is a major shift towards periphytic dominance and a new ecology establishes in Aqualate Mere. This new ecology then appears to persist through to the end of the Period (and core).

6.3.1 Planktonic Expansion

Beginning at 255cm, ca. 300±85 A.D., *C. radiosa* shows a sudden growth period. Climbing from 10% T.D.A., it reaches a core peak of 24% T.D.A. ca. 350±80 A.D. Immediately following *C. dubius* rises from 15% to 40% T.D.A. at ca. 415 A.D. In combination these changes result in a shift in the planktonic/periphytic ratio from 60:40% to 79:21% (Fig. 5.3) and a concurrent rise in the trophic index. This suggests an increase in the productivity of the lake. This, however, runs contrary to the L.O.I., which shows a large fall from 41% to 30% of this period, suggesting decreasing productivity (see Fig. 5.7). At first this would seem counterintuitive, but when magnetics data and pollen data are taken into account this situation begins to explain itself.

From ca. 60±115 B.C. (315cm) in P.2 steady tree, predominately *Quercus*, clearance began in the Aqualate catchment. This progressed until ca. 265±90 A.D. (260cm) where a particularly sharp increase in clearance occurred. Alongside this clearance from ca. 220±90 A.D. was a growth in the HIRM signal and a decrease in the S-ratio and L.O.I. In combination these proxies suggest that catchment deforestation, which began in the late Iron Age, reached a critical point ca. 220±90 A.D., in the Roman period. The consequence of these changes is significant catchment erosion and sediment in-wash into the Mere.

An increase in sediment flux to the lake would explain the succession observed in the diatoms. As sediment entered the lake there would firstly have been increased turbidity (Smol, 2002). This turbidity and in-wash of nutrients would then have favoured plankton over periphytic species, with high nutrient loading particularly favouring the rise in eutrophic *C. dubius*. The reasons for the sequential nature of the peaks in first *C. radiosa* and secondly *C. dubius* are less clear. It may simply be that *C. dubius* is present at higher numbers since it has two bloom periods: in spring and autumn (Bradshaw & Anderson, 2003) as opposed to *C. radiosa* having only one in autumn (Rioual, 2007).

The beginning of P.3 therefore is a story of sediment influx resulting from the apparent intensification of land use in the Roman period. This resulted in the disruption of any stratification that may have developed and a highly turbid polymictic lake. In fact sediment influx would have lead to lake shallowing and hence decreased water depth. This in turn may be the mechanism that prevented any lake stratification explaining the succession observed in diatoms. This plankton dominated system however was short lived and following 415±75 A.D. a second shift occurs, which is discussed over the following pages.

6.3.2 A Significant Perturbation ca. 415±75 - 530±70 A.D.

At ca. 415±75 A.D. (≈240cm) the sediment influx to the lake, represented by the HIRM, reaches a peak, which is concurrent with the peak in *Quercus* clearance. From this point on the HIRM signal gradually declines as *Quercus* pollen begins to recover. Alongside these changes is a crash in *C. dubius* and *C. radiosa*. Both decline to 2% T.D.A., which is reflected in a shift in the planktonic/periphytic ratio to 12:88% at 230cm ca. 530±70 A.D. Coupled with these minima is the rise and peak of *C. ocellata* to 18% T.D.A. at this depth. These changes are highly important as they represent a significant ecological shift in the lake over a period of ca. 115±70 years.

The dating of this period however is highly subjective given the problems with extrapolating calendar dates from radiocarbon dates (Walker, 2005). Furthermore there are indications that the increased sedimentation, inferred from magnetics data, may have led to a high sedimentation rate through this period; making extrapolation of dates even more subjective. Between the depths ca. 250cm and 225cm the charcoal record of Pittam (2006) indicates a complete absence of charcoal. There are two mechanisms by which this could occur: reduced human impact or dilution of charcoal in the palaeo record by mass input of sediment. Reduced human impact would seem an unlikely explanation as the indications from the pollen record are of a period of high human impact. The latter of these explanations, that sedimentation rate, linked to catchment erosion, dramatically increased is the more likely. Taking this into account it is likely that the shift observed between 240cm and 230cm probably

occurred over a shorter space of time than 115±70 years. The question of why the Mere should shift from a planktonic to periphytic dominated system remains.

6.3.3 Alternative Equilibrium

A possible explanation for the changes in the diatom assemblage is the development of an alternative equilibrium (Scheffer *et al*., 1993), a relatively new concept in the ecology of shallow lakes such as Aqualate Mere (Smol, 2002). The hypothesis suggests shallow lakes can exist in two alternative stable equilibria: a clear, aquatic vegetation dominated state, and a turbid phytoplankton dominated state (Scheffer *et al*., 1993). In clear, aquatic vegetational dominated, states lakes can tolerate high nutrient levels, until a critical threshold is reached or a perturbation occurs that forces a change. When such a point is reached, or perturbation occurs, turbidity will climb preventing light reaching aquatic plants. This in turn leads to the development of a turbid plankton dominated state. It is in this, turbid phytoplankton dominated, state that it is proposed Aqualate Mere existed prior to 240cm (ca. 415±75 A.D.). High levels of *C. dubius* and *C. radiosa* are taken as evidence to support this statement. Following 240cm it is proposed that the Mere began a shift towards the alternative, clear macrophyte dominated equilibrium.

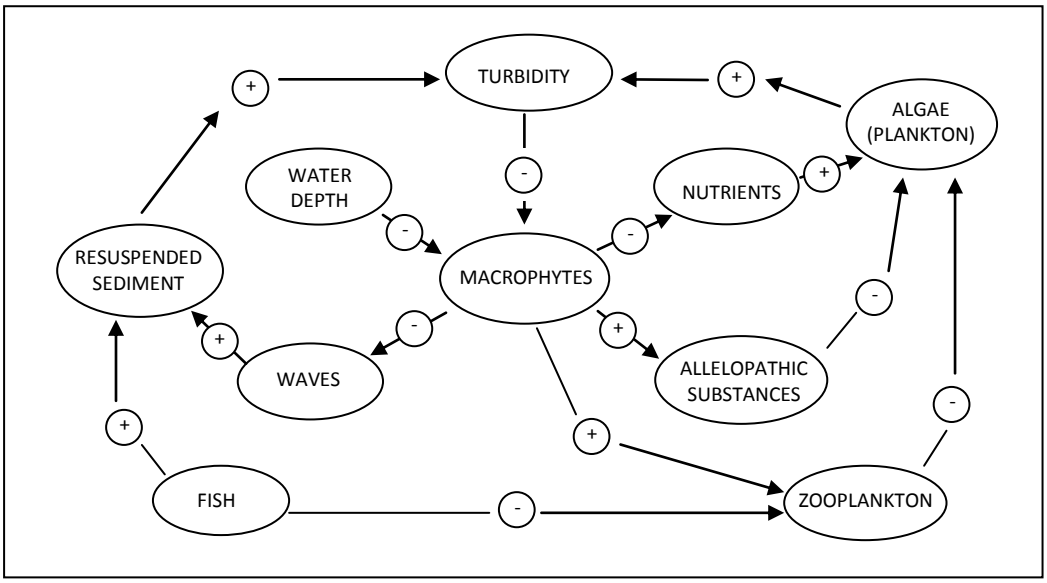

Figure 6.5 The main feedbacks and mechanisms thought responsible for alternative equilibria in shallow lakes such as Aqualate Mere (adapted from Scheffer *et al*., 1993).

Scheffer *et al*. (1993) proposed decreased water levels as a theoretical mechanism for how such as shift could occur. They suggested that in a turbid state a lake can be brought back to a clear state because as water level decreases light penetration will increase. This thereby allows colonisation by aquatic vegetation, regardless of turbidity. The alternative clear, aquatic vegetation dominated state would then develop as vegetation acts to reduce turbidity and counter algal growth. Figure 6.6 highlights the feedback loops and mechanisms that would govern such a process.

With the mechanism and feedbacks for such as shift established it is clear such changes could have caused this switch at Aqualate Mere ca. 415±75 to 530±70 A.D. The potential for water levels to have lowered thereby bringing the lake within the attraction area of a vegetated state could have occurred at Aqualate Mere via two mechanisms. The first of these is relative lowering of lake levels by sediment infilling. Magnetics and pollen data clearly indicate the potential for such delivery and the charcoal reconstruction points towards rapid sedimentation ca. 415±75 to 530±70 A.D. Secondly this period was one of relative warmth (Lamb, 1995; Eronen, 1999; Briffa, 2000). This could have led to the further lowering of water levels as precipitation would have been lower and evaporation would have been higher leading to a net loss of water (Battarbee, 2000).

The mechanisms for water level lowering, which would allow such a shift were therefore in operation at Aqualate Mere between 415±75 and 530±70 A.D. The rise in periphytic species at the expense of plankton, suggests such a shift towards clearer water occurred. As more light penetrated the lake periphytic habitats expanded and the proportion of epontic species also expanded from 5% to 15% T.D.A. Smol (2002) suggests that epontic species can be used as an indicator of aquatic vegetation. Their rise here would therefore support the theory that aquatic vegetation was re-colonising the lake. Further support for this comes from Pittam (2006) which shows an increase in the contribution from aquatic plants through this period.

The rise of *C. ocellata* is interpreted as another indicator of such a shift. As new clear water state developed in the lake there would almost certainly be a period of flux as the shift from predominately periphytic habitats occurred. As a tychoplanktonic taxa

C. ocellata is equally at home in the benthos or plankton and over a wide range of nutrient states (Denys, 1991; Crener & Wagner, 2003; Propenko *et al*., 2007). It is therefore well placed to exploit such uncertainty and its peak in this period is interpreted to be indicative of such. Following the transitional period described above *C. ocellata* rapidly declines towards ca. 640±65 A.D. and a strong assemblage of periphytic species emerge. This is taken as the evidence of the establishment of a clear, shallow, macrophyte dominated system. In particular the rise of *C. placentula*, an epontic species, to a peak of 40% T.D.A. ca. 1000±45 A.D. is evidence of large amounts of aquatic vegetation. The indications from the trophic index and the new periphytic species, such as *G. accuminatum* are that the water is still nutrient rich. However since there are no obvious external perturbations, the lake remains in a relatively clear water state.

It has therefore been established that at the beginning of P.3 that was a significant perturbation to the palaeoecology of Aqualate Mere. This perturbation is ascribed to increased sediment influx to the lake, probably the result of intensification of land use and woodland removal by the Romans. However as has been discussed above there is uncertainty regarding the dating of these changes. The above mentioned perturbation is then followed by stability as an equilibrium state is established (Scheffer *et al*., 1993). This clear water state, dominated by aquatic vegetation once established then appears to continue through the remainder of the core. This however is not the whole story of P.3 and one further period, rather event, of interest occurs in Period 3.

6.3.4 Mediaeval Warming

As was established earlier *C. dubius* declined to a core minimum at the beginning of P.3 ca. 530±70 A.D. However the species did not remain suppressed in this state for long. Following this low the species staged a recovery. At first this recovery was slow: 10% T.D.A. by 195cm, ca. 910±50 A.D. Following this depth, the species surged to a peak of 38% T.D.A. at 180cm, ca. 1085±40 A.D. This was followed by an equally dramatic decline to 13% T.D.A. by 160cm, ca. 1300±30 A.D. Previously growth in this species has been associated with major perturbations in the lake and increased

turbidity. However no other diatoms or proxies indicate such an event between these depths. *C. dubius* must have been responding to some other factor.

The answer to the question of what was causing this growth in *C. dubius* may be in climate. The dates of this expansion probably lie in the so called Mediaeval Warm Period (Lamb, 1995) discussed in Chapter 2; in fact the peak of 38% T.D.A. in C. dubius at 1085 places around the time of peak warmth in this period (Lamb, 1995; Briffa, 2000). This suggests that *C. dubius* was responding to a warming climate and may therefore be a signal for this warm period. Anderson (2000) provides the mechanism for such a signal in *C. dubius* when he suggests that although diatoms are not directly governed by temperature their productivity is. This peak in *C. dubius* around 1085±40 A.D. could therefore be a signal of warmer weather, which instigated significantly larger blooms of *C. dubius* through this period; leading to an increased presence in the assemblage through these depths. Once the warm period had passed *C. dubius* did not bloom as intensely and so its abundance began to decline to the lower levels expected in a clear, macrophyte dominated lake. This event could therefore be the clearest signal yet of a known climatic event in the whole record of Aqualate Mere.

7.0 Conclusions

7.0 Introduction

The overall aim of the study was to reconstruct the palaeoecological history of Aqualate Mere through the reconstruction of diatom species assemblage changes. Secondary to this was to set the changes within the chronological framework established by Pittam (2006). The changes were then interpreted alongside changes identified in pollen and magnetics reconstruction from the said work. The following chapter will evaluate the project with reference to this overall aim and objectives set out in Chapter 1. Each will be discussed in turn and the successes and failures will be highlighted. Additionally the chapter will propose further avenues of enquiry that have been highlighted by the research.

7.1 **Objective 1:** to investigate human impacts on the palaeoecology of Aqualate Mere and determine if they are the predominant forcing variable on the paleoecology of the lake.

This objective was initially explored in Chapter 5 and further explored in Chapter 6. Clear links between changes in the diatom stratigraphy and pollen and magnetics record have been established. Congruence between changes in the diatoms in relation to certain pollen zones was noted; however this was at best inconclusive. Examples of such links between inferred human activity and palaeoecology change in the mere include the two major perturbation events, both linked to deforestation:

1. The first of these events occurred in P.1 ca. 850±190 B.C. and it was difficult to distinguish if changes in diatom palaeoecology at this depth were solely linked to human activity. The period was one of climatic deterioration as such it is concluded that the changes may represent climatic forcing filtered through human activity.

2. The second of these major perturbations peaked in P.3 at ca. 530±70 A.D. Although there are indications that this event began earlier. The changes at this depth can be clearly ascribed to human activity given the strong signals of human activity in the Aqualate catchment and the slight lag in response from the diatoms. Although this period was again one of climatic deterioration the indications are that the factors causing the perturbation, namely deforestation and soil erosion began much earlier. It is concluded that this perturbation is clearly linked and is the strongest signal of anthropogenic impacts upon Aqualate Mere.

Besides these two perturbations the links between human activity and diatom palaeoecology are less clear. There are undoubted similarities in the timings of certain events, such as the rise in *S. rotula* in the mid part of P.2 and the changes in magnetic signatures. However such events are not as clear as the perturbations described and cannot be definitively said to have caused the other. As a result is has not been possible to establish if human activities are the predominant forcing variable for the changes observed in the palaeoecological record. What can be said however is that this seems unlikely to be the case. Rather human impacts are an ad-mixture of direct impacts and climatic influences filtered through human activity.

The objective has therefore been partially achieved with certain links clearly illustrated. The goal of determining if human activity is the ultimate driver of such changes, with the most influence on the paleoecology of Aqualate Mere remains elusive. This was not unexpected as lowland catchments have been within the influence of human populations for at least the last 3000 years (Barber *et al.*, 1999). Furthermore it is in agreement with Battarbee (2000) who stated that separating anthropogenic signals from climatic ones is one of the biggest challenges in using lakes to investigate past climate change.

7.2 **Objective 2:** to investigate the role of climate on the palaeoecology of Aqualate Mere and establish if there is evidence for the diatom community responding to established climatic cycles such as those identified by Bond (1997; 2001) or events such as those summarised in Berglund (2003).

This objective was primarily investigated in Chapter 5. In this chapter attempts were made to tie changes in the palaeoecological record to dates and investigate the relative importance of climate and human forcing. Evidence for climatic forcing of the palaeoecology of Aqualate Mere was noted to be present throughout the core. However disentangling such signals from those of human impact has proved difficult (Battarbee, 2000). The findings of this study suggest that climate has been a constant force affecting the palaeoecology of Aqualate Mere throughout its history. Despite this there are few times when it can be ascribed as the sole force.

Evidence for climatic forcing at Aqualate Mere is present in three key ways. Firstly direct climate impacts, such as those towards the end of P.1, where there are clear indications of wind driven mixing and increasing nutrients. Another example of such impacts may be the rise of *C. dubius* ca. 1000±45 A.D. in the mediaeval period. Secondly are those which have been described here as human mediated climate impacts. An example of such a change comes around 850±190 B.C.: a known climatic deterioration (Lamb, 1995; van Geel, 1996; Berglund, 2003) where there is a clear signal of disruption to the palaeoecology of Aqualate Mere following deforestation. The human activity in the catchment around this time is postulated to be forced by climate. Thirdly are the times when climate is not so much forcing as setting the conditions that allow the development of aspects of the palaeoecology. An example of this comes from P.2 where there are possible, although unlikely, indications of seasonal stratification of the lake inferred from the diatom record. Here it is suggested that as climate ameliorated it allowed such conditions to develop rather than force them.

A secondary part of objective 2 was to investigate evidence for responses to extreme climatic forcing events; such as Bond Events (Bond *et al*., 1997). It was proposed that being a relatively large lake Aqualate Mere would be more likely to record large scale climatic disturbances (Battarbee, 2000; Cohen, 2003). As was discussed above, such events or changes have potentially been identified in the palaeoecological record. There are indications of an impact from Bond Event 2 ca. 850 B.C. and furthermore then are signs of the diatom *C. dubius* responding to mediaeval warming ca. 1085±35 A.D.

The successes of investigating Objective 2 therefore are similar to those of Objective 1. Climatic forcing has been identified and demonstrated in the palaeoecological record. Unfortunately it has not always been possible to definitively ascribe changes to climate over human impacts or *vice versa*. There have also been tentative successes in identifying shifts in diatoms around the time of climate cycles such as Bond Event 2. However to definitively ascribe causal links will require higher resolution sampling and closer chronological control of such changes.

7.3 **Objective 3:** To investigate the trophic history of the lake and investigate the hypothesis that increases in Anabaena are the result of nutrient enrichment as a result of increasing anthropogenic impact (Pittam, 2006). Or were large blue-green algae blooms inferred by Pittam (2006) actually natural phenomena, common in the West Midland Meres (Reynolds, 1979; McGowan *et al*., 1999).

Resolving the trophic history of Aqualate Mere was in many ways a microcosm of Objectives 1 and 2. The objective was explored in detail in Chapter 6 on the discussion of Period 2 where an intense period of eutrophication of the lake was inferred from diatoms and other proxies. It was the investigation of this objective that produced the clearest conclusions.

Eutrophication inferred from *Anabaena* fossils identified by Pittam (2006) is suggested to be a result of anthropogenic forcing. However the findings of this work suggest it to be a natural development in Aqualate Mere, which is in agreement with McGowan *et al*. (1999). The diatom assemblage suggested that the lake has been broadly meso-eutrophic since at least the late Bronze Age and in all likelihood a lot longer. Furthermore the cyanobacterial Anabaena blooms when interpreted alongside diatom data could suggest some development of seasonal stratification as the cause for their presence. The impacts of anthropogenic activity are, not discounted however, but are considered to exacerbate such eutrophication rather than drive it.

This objective has therefore been largely successful with the two hypothesis apparently resolved. Although there have been successes there still remains

uncertainty as to the scale with which human activity may have amplified, what are suggested here to be natural processes. This is something that cannot be easily resolved from the available proxy data. Investigation of this objective has therefore produced some interesting results worthy of further investigation.

7.2 Avenues for Further Research

As this work has answered some of the questions it set out to resolve it has inevitably raised new ones. The following section is a discussion of the proposed avenues for further research. Firstly further research is proposed to answer questions not fully resolved in this work. Secondly avenues for additional lines of enquiry into the palaeoecology of Aqualate Mere are proposed.

7.2.1 Increasing Resolution

One of the key limitations of this work was the lack of sampling resolution. Between the depths 490cm and 245cm sampling at 5cm intervals was extrapolated from radiocarbon dating to represent ca. 30 year intervals. Further up the core between 245cm and 130cm resolution became even longer. Between these depths 5cm intervals were extrapolated to be ca. 55 years. Clearly this represents a long time interval and many changes may be occurring in this time slice, which have not be identified. Further work to address this low resolution should therefore be pre-eminent in any further research. Such sampling should initially target the key perturbations between 465cm and 450cm and 250cm to 210cm and then progress to increasing resolution throughout the core. A secondary aspect to such increased sampling resolution would be to increase chronological control through the procurement of additional radiocarbon dates. A combination of these two would thereby allow a greater understanding of the changes occurring at these depths.

7.2.2 Additional Proxies

Beyond addressing the questions surrounding sampling resolution the addition of additional proxies is proposed. In Chapter 6 it was proposed that an increase in the

χARM/SIRM ratio was a possible indicator of anoxia. This could be further investigated by geochemical analysis of the sediments measuring Fe:Mn ratios as pioneered by Mackereth (cited in Smol, 2002). This technique is based on the principal that both of these elements become soluble in reducing conditions. In anoxic conditions Fe and Mn would be mobilised into the lake water, with Mn becoming more soluble than Fe. Mackereth (1966) reconstructed the ratios of the elements and was able to demonstrate they could be used to reconstruct rudimentary palaeo-redox levels. Geochemical analyses could also be used to directly investigate the presence of other elements including N and P to quantitatively investigate the trophic history of the lake. Another potentially useful proxy that could be investigated would be chironomid assemblages, should they be preserved. These could be used to investigate trophic history, both directly and through a qualitative reconstruction of past dissolved oxygen levels (Smol, 2002). A further use would be to further investigate the hypothesis that ca. 530 A.D. Aqualate Mere shifted to a clear macrophyte dominated system. Work by Broderson et al. (2001) correlated distinct chironomid assemblages with specific macrophyte classes. Chironomids could potentially work to investigate the past macrophytes in a similar way from the sediments of Aqualate Mere.

7.2.3 Extending the Chronology

A final area of further research is proposed: to extend the palaeo reconstruction of Aqualate Mere. Pittam (2006) proved the underlying organic deposits of the Mere to a depth of ca. 12m, without proving the base. This suggests that potentially a full Holocene sequence exists. It is proposed that extending the reconstructions further back in time would potentially allow Aqualate Mere to become a key reference site for Holocene change in the Midlands. Furthermore it would allow more detailed investigation of the trophic history back in investigate the impact of humans back into the Bronze Age and Neolithic. Such work would also allow for investigation of whether the mere has always been broadly eutrophic.

7.3 Summary

This investigation has succeeded in investigating the palaeoecological history of Aqualate Mere. The strength of diatoms as a tool for such investigation has been illustrated as has the use of the multi-proxy approach. However the resolution of the relative influence of climate and human activity of forcing variables has not been fully resolved. Despite this the study has increased the understanding of palaeoecological change in the English Midlands and the meres of the English Midlands in particular.

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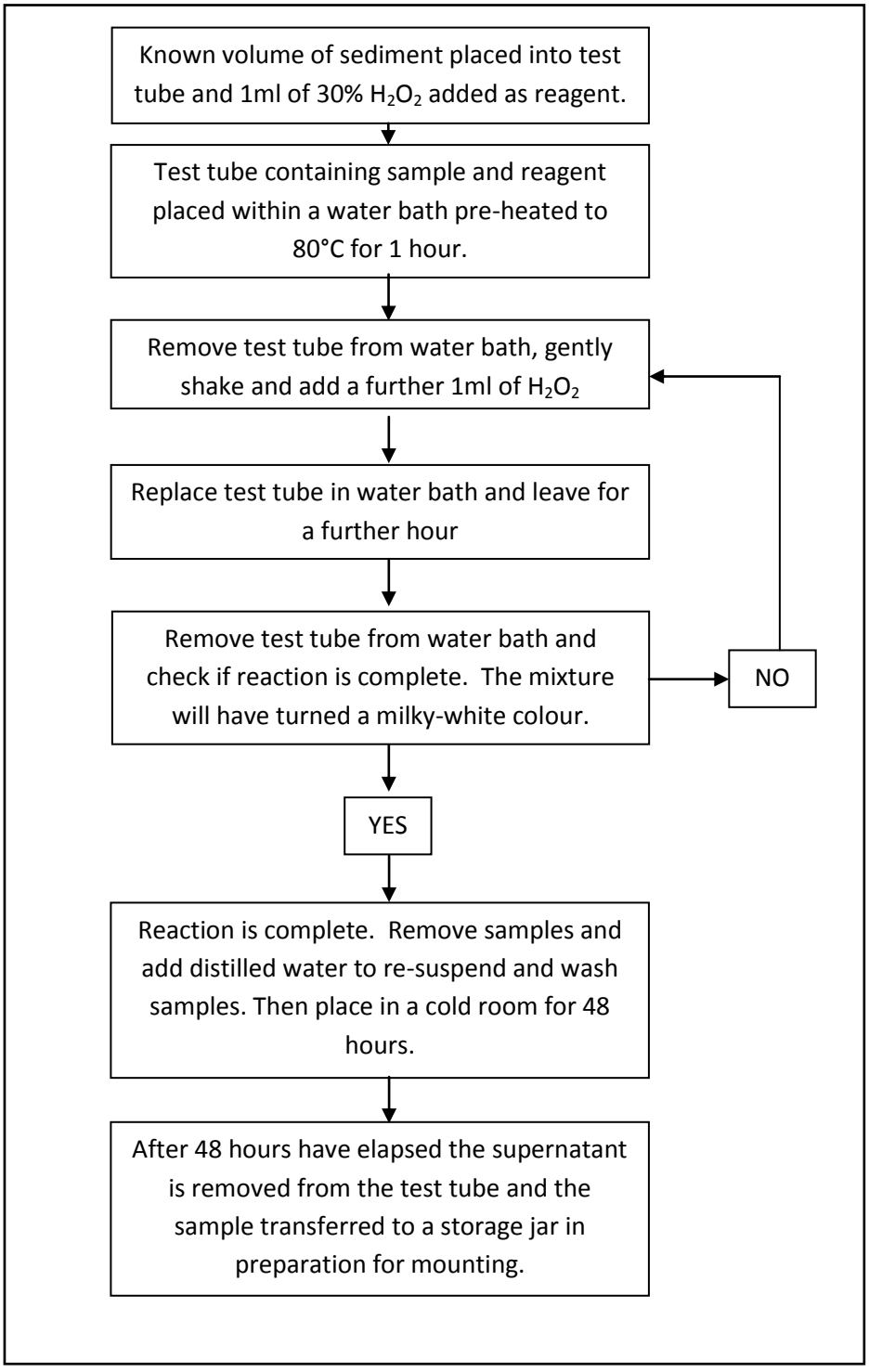
9.0 Appendix

9.0 Diatom Extraction Protocol



9.1 Laboratory Risk Assessment

For the Production of Diatom Microscope Slides

Hazard	Risk	Control Measures
Hydrogen Peroxide (a bleaching agent and skin irritant)	Skin contamination	• Gloves should be worn when handling. • Wash hands after removing gloves. • Clean contaminated pipettes after use. • Wear a lab coat when handling.
Naphrax (slide mounting media containing Toluene: a carcinogen)	Skin contamination	• Gloves should be worn when handling. • Wash hands after removing gloves. • Clean contaminated pipettes after use. • Wear a lab coat when handling.
Naphrax (slide mounting media containing Toluene: a carcinogen)	Inhalation of toxic fumes	• Naphrax must only be used within a fume cupboard. • Slides should not be removed from the fume cupboard until completely cool.
Hot plate (set at 130°C)	Burns to arms and forearms	• Use tweezers to place and remove slides from the hotplate. • If leaving hotplate switched on and unattended place a sign to indicate danger.

9.2 Raw Diatom Counts

	Depth (cm)								
DIATOM	**130**	**135**	**140**	**145**	**150**	**155**	**160**	**165**	**170**
Achanates ostruepii	0	5		2	1	2			
Amphora libyca	1		3	3	1	2	4	3	4
Amphora exima		2		1					
Asterionella formosa	1	2	3		3				15
Aulacoseira distans									
Aulacoseira islandica	3	14	3	16	15	25	20	16	5
Aulacoseira italica	6	2	4	2	17	4	14	4	4
Camphylodiscus hiberncus									
Cocconeis placentula	13	19	16	24	21	44	16	56	30
Cyclostella bodanica (var. affins)	3	2	7	4	5		16	2	2
Cyclostephanos costalimbus	11	8	11	7	1	3	1	8	
Cyclostephanos dubius	23	19	21	15	30	37	40	42	66
Cyclotela planktonica									
Cyclotella ocelatta	4	10	2	7	3	5	5	5	3
Cyclotella radiosa	36	13	18	27	17	31	19	28	15
Cymbella aspera		1				1		1	
Cymbella cistula					2				1
Cymbella cistula (var. maculta)								1	
Cymbella silesiacum								1	3
Diatoma ancers									
Diploneis elliptica	6	1	1	1	3	1	1		2
Epithemia adnata (var. porcellus)									
Epithemia argus		3	1	5	3	10	11	4	5
Eunotia elegans	2	1	1	1	3	1	5		3
Eunotia vanheurckii									
Fragilaria arcus									
Fragilaria brevistriata	23	19	29	29	22	16	29	25	25
Fragilaria capucina		2		6	1	8	4	4	11
Fragilaria construens	140	122	146	93	97	66	81	61	60
Fragilaria construens (var. exigua)		1							
Fragilaria leptosauron									2
Fragilaria parasitica	1	1	1		1		1		
Fragilaria pinnata	4	10	6	11	3	6	5	4	2
Fragilaria reicheltii									
Fragilaria robusta		1	1	2	2			1	
Fragilaria ulna									
Fragilaria virencens	6		7		11				
Fragilaria zellieri									
Gomphonema groveii		2				1		2	3
Gomponema acuminatum			1						
Gyrosigma accuminatum	10	17		23	7	13	10	10	12
Navicula atomus	1	7	9			2		4	7
Navicula capitata						2	1		
Navicula cincta	6	10	3	7	14	3	7	3	4
Navicula cocconeisformis									
Navicula cryptonella		2	4	2	7	4	2		5
Navicula detenta			1		1		1		2
Navicula orbis									
Navicula peregrina									
Navicula scutelloides		5		3	2	3	1	2	1
Navicula simplex	1	1		3				4	
Nitzchizia sp. I									
Pinnularia microstauron		1		2		1		2	
Rhoicosphenia curvata									
Stauroneis muriella		1		1		2			
Stauroneis acuta									
Stephanodiscus rotula	1				1	1	2		2
Suriella ovalis		1		1		3			
Taballiera flocculosa									
Taballiera ventricosa			3						1
Unknown V	2			3	6	5	5	5	6

	Depth (cm)								
DIATOM	**175**	**180**	**185**	**190**	**195**	**200**	**205**	**210**	**215**
Achanates ostruepii		1		1	4	5	3	4	3
Amphora libyca	11		3		3	1	5	3	6
Amphora exima			2	2	4				
Asterionella formosa		2		12	1	6	1	3	
Aulacoseira distans									
Aulacoseira islandica	9	2	11	4	12		14	1	13
Aulacoseira italica	7	3	11	3	3	5	6	8	3
Camphylodiscus hiberncus		6	1						2
Cocconeis placentula	59	11	97	20	47	12	30	18	38
Cyclostella bodanica (var. affins)		5		6	4	10	5	4	
Cyclostephanos costalimbus	5	3	8	12	6	2		1	
Cyclostephanos dubius	72	112	36	52	30	29	24	22	22
Cyclotela planktonica									
Cyclotella ocelatta			9	2	1	1			10
Cyclotella radiosa	20	12	10	5	17	26	12	28	28
Cymbella aspera	2		3		3				2
Cymbella cistula		1							
Cymbella cistula (var. maculta)		5							
Cymbella silesiacum	1		1		2				1
Diatoma ancers									
Diploneis elliptica	2	3	1	4	4	4	1	7	2
Epithemia adnata (var. porcellus)									
Epithemia argus	8	1	15	2	5	1	5	1	2
Eunotia elegans	5	2	1	1	1	4	2	1	2
Eunotia vanheurckii								1	
Fragilaria arcus							3		2
Fragilaria brevistriata	37	40	37	43	35	26	29	30	22
Fragilaria capucina	6		5		10		17	2	7
Fragilaria construens	28	56	23	62	50	101	44	98	36
Fragilaria construens (var. exigua)				2					
Fragilaria leptosauron					1				
Fragilaria parasitica		5	2	5					
Fragilaria pinnata	7	2	1	4	4	5	11	7	6
Fragilaria reicheltii		5							
Fragilaria robusta	1	1	3	2					
Fragilaria ulna						2			
Fragilaria virencens		3		5		9		8	
Fragilaria zellieri		1							
Gomphonema groveii	2	3	4	2	1			1	
Gomponema acuminatum		1			1			1	
Gyrosigma accuminatum	7	4	1	5	20	11	16	5	23
Navicula atomus	2	5	3	9	2	2	3	5	7
Navicula capitata									
Navicula cincta	2	3	2	7	2	7	4	8	12
Navicula cocconeisformis									
Navicula cryptonella		3	1	9	6	7	8	10	4
Navicula detenta		2				2			2
Navicula orbis									
Navicula peregrina									
Navicula scutelloides	1	1	1	3	7	11	36	6	18
Navicula simplex	1	1	5	6				6	
Nitzchizia sp. I							2		
Pinnularia microstauron	1						3		1
Rhoicosphenia curvata			1						1
Stauroneis muriella						1	4		
Stauroneis acuta									
Stephanodiscus rotula		3		5	3	6	10	6	8
Suriella ovalis	3		4		6		2		13
Taballiera flocculosa				1				3	
Taballiera ventricosa				1		1			
Unknown V					5			1	3

	Depth (cm)								
DIATOM	**220**	**225**	**230**	**235**	**240**	**247**	**250**	**255**	**260**
Achanates ostruepii	3	6		1	1			2	2
Amphora libyca	3	5		7		4		10	
Amphora exima			5						
Asterionella formosa	4	1	1			2	3	1	
Aulacoseira distans									
Aulacoseira islandica	1	11		10		8	6	10	12
Aulacoseira italica	5	1		3		1	12	14	22
Camphylodiscus hiberncus		3		8	2	6		3	
Cocconeis placentula	28	25	26	20	9	19	13	18	8
Cyclostella bodanica (var. affins)	4				9	5	3	6	14
Cyclostephanos costalimbus	17		23	2	13	15	13	14	3
Cyclostephanos dubius	17	20	9	27	121	45	73	47	45
Cyclotela planktonica								1	
Cyclotella ocelatta	3	22	56	30	21	16	9	7	1
Cyclotella radiosa	24	23	7	21	48	70	21	30	22
Cymbella aspera		4		1	2			4	
Cymbella cistula	2					2			1
Cymbella cistula (var. maculta)									
Cymbella silesiacum		4		5		1			
Diatoma ancers									
Diploneis elliptica	2		1	1		5		1	
Epithemia adnata (var. porcellus)									
Epithemia argus	1	6	3	8	2	3	1	5	
Eunotia elegans	3	3		1	1	3		2	
Eunotia vanheurckii					1				
Fragilaria arcus		1							1
Fragilaria brevistriata	32	34	34	37	12	25	17	27	30
Fragilaria capucina	1	7		5	1	6		1	3
Fragilaria construens	91	59	64	46	29	28	73	48	80
Fragilaria construens (var. exigua)									
Fragilaria leptosauron							1		
Fragilaria parasitica			1				1	1	1
Fragilaria pinnata	4	4	1	3	2	6	1	1	2
Fragilaria reicheltii									
Fragilaria robusta	1	3	4	1	2			2	
Fragilaria ulna			3	3	2				
Fragilaria virencens	8						5		
Fragilaria zellieri									
Gomphonema groveii		1	4	10	1	1	2		1
Gomponema acuminatum									
Gyrosigma accuminatum	6	14		10	4	5	4	9	11
Navicula atomus	2		22	4	3	6	5	6	5
Navicula capitata				2					
Navicula cincta	8	4	27	11	7	6	20	10	7
Navicula cocconeisformis	5								
Navicula cryptonella	2	6	8	2	1	1	2	3	9
Navicula detenta	3					1		2	3
Navicula orbis									
Navicula peregrina									
Navicula scutelloides	10	7	2	3	1	2			
Navicula simplex	5	2	6	1		1		2	8
Nitzchizia sp. I				5					
Pinnularia microstauron									
Rhoicosphenia curvata		1				1			
Stauroneis muriella				1		2	2	4	
Stauroneis acuta			1				1		
Stephanodiscus rotula	4	3	1	2	7	5	11	12	19
Suriella ovalis		14							
Taballiera flocculosa									
Taballiera ventricosa									
Unknown V	2			3					

	Depth (cm)								
DIATOM	**265**	**270**	**275**	**280**	**284**	**290**	**295**	**300**	**305**
Achanates ostruepii	5	5	1		1		1		2
Amphora libyca			2			1	3		
Amphora exima	4		6						4
Asterionella formosa	2		8	1		2			3
Aulacoseira distans									
Aulacoseira islandica	11	11	31	7	16	25	25	9	21
Aulacoseira italica	13	17	6	9	10	24	19	5	16
Camphylodiscus hiberncus									
Cocconeis placentula	18	11	8	12	23	9	9	13	17
Cyclostella bodanica (var. affins)	19	17	19	8	24	9	15	10	8
Cyclostephanos costalimbus	11		7	6		4	5	4	
Cyclostephanos dubius	50	60	70	59	88	65	82	70	83
Cyclotela planktonica	1								
Cyclotella ocelatta					2	1	1	1	3
Cyclotella radiosa	28	24	35	16	22	20	15	12	19
Cymbella aspera									1
Cymbella cistula	2	1							
Cymbella cistula (var. maculta)									
Cymbella silesiacum									
Diatoma ancers					1				
Diploneis elliptica				1					2
Epithemia adnata (var. porcellus)					1				
Epithemia argus	4	1	1		4	5	5	2	5
Eunotia elegans	2				2		1		1
Eunotia vanheurckii	2	3	3		1	1			
Fragilaria arcus									
Fragilaria brevistriata	25	22	24	23	18	17	29	26	30
Fragilaria capucina	3	8	5	3	6		4		3
Fragilaria construens	45	56	31	111	40	76	32	88	41
Fragilaria construens (var. exigua)									
Fragilaria leptosauron								3	
Fragilaria parasitica	2	1		2					
Fragilaria pinnata		3						1	
Fragilaria reicheltii									
Fragilaria robusta		4	1	2	2	1	2	3	
Fragilaria ulna			2					3	
Fragilaria virencens								3	1
Fragilaria zellieri						2			
Gomphonema groveii	5	1	1				1		1
Gomponema acuminatum									
Gyrosigma accuminatum	6	4	6	7	6	3	5	3	4
Navicula atomus	6		6	6	3	4	8	8	1
Navicula capitata		1	2				1		
Navicula cincta	11	6		4	9	5	10	5	1
Navicula cocconeisformis									
Navicula cryptonella	2	5	5	6	7	4	4	6	3
Navicula detenta	2		2		1		2		2
Navicula orbis		6							
Navicula peregrina									
Navicula scutelloides									
Navicula simplex	1	3		2	1	2	1		
Nitzchizia sp. I									
Pinnularia microstauron									
Rhoicosphenia curvata									
Stauroneis muriella				2	1	1			
Stauroneis acuta									
Stephanodiscus rotula	17	15	19	14	19	18	30	29	34
Suriella ovalis									
Taballiera flocculosa									
Taballiera ventricosa	1								
Unknown V	2								

	Depth (cm)								
DIATOM	**310**	**315**	**320**	**325**	**330**	**335**	**339**	**345**	**350**
Achanates ostruepii							3		
Amphora libyca		2		1	2		3	1	1
Amphora exima						2			
Asterionella formosa	2	1	2	2	3		5		5
Aulacoseira distans			1						
Aulacoseira islandica	6	7	12	27	9	9	9	6	9
Aulacoseira italica	4	7	14	14	4	11	28	27	18
Camphylodiscus hiberncus						1			
Cocconeis placentula	8	8	9	13	12	16	19	16	12
Cyclostella bodanica (var. affins)	7	7	15	11	9	18	20	27	6
Cyclostephanos costalimbus	4	9	11	16	3	2	2	7	6
Cyclostephanos dubius	80	70	76	78	96	101	106	93	89
Cyclotela planktonica									
Cyclotella ocelatta		1	1	3	8				
Cyclotella radiosa	18	15	16	12	33	23	21	20	39
Cymbella aspera									
Cymbella cistula				1					
Cymbella cistula (var. maculta)									
Cymbella silesiacum									
Diatoma ancers									
Diploneis elliptica	2		1						
Epithemia adnata (var. porcellus)									
Epithemia argus	1	6				1			1
Eunotia elegans								2	
Eunotia vanheurckii	1				3			1	5
Fragilaria arcus									
Fragilaria brevistriata	23	42	13	26	19	18	9	17	15
Fragilaria capucina	1	6		2	2	4	5	2	2
Fragilaria construens	87	65	66	30	59	38	22	29	51
Fragilaria construens (var. exigua)									
Fragilaria leptosauron	3		1		2				
Fragilaria parasitica	2		1					2	
Fragilaria pinnata	1	1		1			2		
Fragilaria reicheltii									
Fragilaria robusta			2						
Fragilaria ulna	3	1	1			1			
Fragilaria virencens		4	2	5				5	1
Fragilaria zellieri					2				
Gomphonema groveii	1	1	3		2	2			4
Gomponema acuminatum									
Gyrosigma accuminatum	8	3	3	3	3	2	1	3	2
Navicula atomus		1	1	3	1	4	4	3	3
Navicula capitata									
Navicula cincta	6	5	8	8	6	8	2	5	7
Navicula cocconeisformis									
Navicula cryptonella	5	1		1	6	1	3		
Navicula detenta		1				2	1		
Navicula orbis									1
Navicula peregrina									
Navicula scutelloides	1								
Navicula simplex	2		1				1	1	1
Nitzchizia sp. I									
Pinnularia microstauron									
Rhoicosphenia curvata									
Stauroneis muriella		1							2
Stauroneis acuta									
Stephanodiscus rotula	28	44	45	45	27	39	31	33	22
Suriella ovalis									
Taballiera flocculosa									
Taballiera ventricosa									
Unknown V							2		

	Depth (cm)								
DIATOM	**355**	**360**	**365**	**370**	**375**	**380**	**385**	**390**	**395**
Achanates ostruepii			1			1		1	
Amphora libyca			1		3				
Amphora exima			1			4		2	
Asterionella formosa	2	1	2	1		3	1		1
Aulacoseira distans									
Aulacoseira islandica	20	18	11	4	12	24	9	8	15
Aulacoseira italica	24		20		25	31	22	17	31
Camphylodiscus hiberncus					1		1	2	4
Cocconeis placentula	10	16	18	18	13	23	18	34	16
Cyclostella bodanica (var. affins)	28	15	21	17	27	10	7	4	1
Cyclostephanos costalimbus	1	5	14	14	6	4	16	8	12
Cyclostephanos dubius	119	95	111	100	96	118	112	128	151
Cyclotela planktonica									
Cyclotella ocelatta	3					1	1	2	1
Cyclotella radiosa	30	40	38	46	43	21	26	15	20
Cymbella aspera									
Cymbella cistula									2
Cymbella cistula (var. maculta)									
Cymbella silesiacum									
Diatoma ancers									
Diploneis elliptica		1			2				1
Epithemia adnata (var. porcellus)									
Epithemia argus	1		4	1	4		3	2	2
Eunotia elegans	4			1		3	1	2	
Eunotia vanheurckii	1	1	1	1					
Fragilaria arcus									
Fragilaria brevistriata	7	15	8	12	4	5	7	11	
Fragilaria capucina	3	2	2		2	2	2	4	
Fragilaria construens	25	49	16	33	45	18	43	33	17
Fragilaria construens (var. exigua)								1	
Fragilaria leptosauron									
Fragilaria parasitica									
Fragilaria pinnata				2	2	8		5	
Fragilaria reicheltii									
Fragilaria robusta									
Fragilaria ulna	2		1				4		
Fragilaria virencens		5			1				3
Fragilaria zellieri								1	
Gomphonema groveii						1			
Gomponema acuminatum	1								
Gyrosigma accuminatum		1	2	6	3	3	3	1	1
Navicula atomus	1	5	1	4	1		4		4
Navicula capitata			1						
Navicula cincta	2	9	2	7	3	2	9	3	4
Navicula cocconeisformis									
Navicula cryptonella	1	4	1	7	3	2	3	1	1
Navicula detenta						1	1		
Navicula orbis									
Navicula peregrina				2					
Navicula scutelloides									
Navicula simplex	2	2	1	1		2	1	1	1
Nitzchizia sp. I						1			
Pinnularia microstauron									
Rhoicosphenia curvata								1	
Stauroneis muriella		2					1		2
Stauroneis acuta									
Stephanodiscus rotula	16	17	23	21	11	15	3	15	8
Suriella ovalis									
Taballiera flocculosa									
Taballiera ventricosa									
Unknown V							2		

	Depth (cm)								
DIATOM	**400**	**405**	**410**	**415**	**420**	**425**	**430**	**435**	**440**
Achanates ostruepii	1		2				5		13
Amphora libyca	1								4
Amphora exima	2					2	2		4
Asterionella formosa			1	4	7	2	1		
Aulacoseira distans									
Aulacoseira islandica	7	3	5	8	3	7	3	8	
Aulacoseira italica	13	23	14	11	18	13	16	8	4
Camphylodiscus hiberncus	4	1	2	2	4	3	1	2	
Cocconeis placentula	33	22	28	16	23	18	18	31	25
Cyclostella bodanica (var. affins)	7	4	2				3		2
Cyclostephanos costalimbus	20	8	26	31	37	34	29	32	22
Cyclostephanos dubius	125	169	150	154	126	140	109	64	66
Cyclotela planktonica									
Cyclotella ocelatta	1	1	3	1		1		3	14
Cyclotella radiosa	21	21	12	15	3	3	2	4	3
Cymbella aspera									
Cymbella cistula					3		1		3
Cymbella cistula (var. maculta)									
Cymbella silesiacum	1								
Diatoma ancers									
Diploneis elliptica	2		2	2	1	1	5	5	1
Epithemia adnata (var. porcellus)									
Epithemia argus		1	1	4	2	7	2	6	
Eunotia elegans		1		4		1			
Eunotia vanheurckii								5	
Fragilaria arcus									
Fragilaria brevistriata	5	5	3	9	3	19	4	37	31
Fragilaria capucina	2	2	3	2	1	1		2	
Fragilaria construens	29	26	22	25	43	37	62	73	69
Fragilaria construens (var. exigua)									
Fragilaria leptosauron									1
Fragilaria parasitica						1			
Fragilaria pinnata	4		7	1	8	1	6	9	17
Fragilaria reicheltii									
Fragilaria robusta									1
Fragilaria ulna									
Fragilaria virencens									
Fragilaria zellieri	1								
Gomphonema groveii				1	1	1	9		
Gomponema acuminatum	4								
Gyrosigma accuminatum	1	5		1		2	1	4	1
Navicula atomus		3	1	3	1	2		4	
Navicula capitata						1			
Navicula cincta	2	1	5	5	5	3	1	6	6
Navicula cocconeisformis									
Navicula cryptonella	2	3	2	7	2	2	2	2	2
Navicula detenta		1				1	1		
Navicula orbis									
Navicula peregrina									
Navicula scutelloides									3
Navicula simplex		2	4		1		1		
Nitzchizia sp. I	1				1				
Pinnularia microstauron									
Rhoicosphenia curvata	1				1		1		1
Stauroneis muriella	1				1		3		2
Stauroneis acuta									
Stephanodiscus rotula	13		12	6	7		15		3
Suriella ovalis									
Taballiera flocculosa									
Taballiera ventricosa									
Unknown V									

9.3 Percentage Diatom Counts

	Depth (cm)								
DIATOM	**130**	**135**	**140**	**145**	**150**	**155**	**160**	**165**	**170**
Achanates ostruepii	0	2	0	1	0	1	0	0	0
Amphora libyca	0	0	1	1	0	1	1	1	1
Amphora exima	0	1	0	0	0	0	0	0	0
Asterionella formosa	0	1	1	0	1	0	0	0	5
Aulacoseira distans	0	0	0	0	0	0	0	0	0
Aulacoseira islandica	1	5	1	5	5	8	7	5	2
Aulacoseira italica	2	1	1	1	6	1	5	1	1
Camphylodiscus hiberncus	0	0	0	0	0	0	0	0	0
Cocconeis placentula	4	6	5	8	7	15	5	19	10
Cyclostella bodanica (var. affins)	1	1	2	1	2	0	5	1	1
Cyclostephanos costalimbus	4	3	4	2	0	1	0	3	0
Cyclostephanos dubius	8	6	7	5	10	12	13	14	22
Cyclotela planktonica	0	0	0	0	0	0	0	0	0
Cyclotella ocelatta	1	3	1	2	1	2	2	2	1
Cyclotella radiosa	12	4	6	9	6	10	6	9	5
Cymbella aspera	0	0	0	0	0	0	0	0	0
Cymbella cistula	0	0	0	0	1	0	0	0	0
Cymbella cistula (var. maculta)	0	0	0	0	0	0	0	0	0
Cymbella silesiacum	0	0	0	0	0	0	0	0	1
Diatoma ancers	0	0	0	0	0	0	0	0	0
Diploneis elliptica	2	0	0	0	1	0	0	0	1
Epithemia adnata (var. porcellus)	0	0	0	0	0	0	0	0	0
Epithemia argus	0	1	0	2	1	3	4	1	2
Eunotia elegans	1	0	0	0	1	0	2	0	1
Eunotia vanheurckii	0	0	0	0	0	0	0	0	0
Fragilaria arcus	0	0	0	0	0	0	0	0	0
Fragilaria brevistriata	8	6	10	10	7	5	10	8	8
Fragilaria capucina	0	1	0	2	0	3	1	1	4
Fragilaria construens	47	41	49	31	32	22	27	20	20
Fragilaria construens (var. exigua)	0	0	0	0	0	0	0	0	0
Fragilaria leptosauron	0	0	0	0	0	0	0	0	1
Fragilaria parasitica	0	0	0	0	0	0	0	0	0
Fragilaria pinnata	1	3	2	4	1	2	2	1	1
Fragilaria reicheltii	0	0	0	0	0	0	0	0	0
Fragilaria robusta	0	0	0	1	1	0	0	0	0
Fragilaria ulna	0	0	0	0	0	0	0	0	0
Fragilaria virencens	2	0	2	0	4	0	0	0	0
Fragilaria zellieri	0	0	0	0	0	0	0	0	0
Gomphonema groveii	0	1	0	0	0	0	0	1	1
Gomponema acuminatum	0	0	0	0	0	0	0	0	0
Gyrosigma accuminatum	3	6	0	8	2	4	3	3	4
Navicula atomus	0	2	3	0	0	1	0	1	2
Navicula capitata	0	0	0	0	0	1	0	0	0
Navicula cincta	2	3	1	2	5	1	2	1	1
Navicula cocconeisformis	0	0	0	0	0	0	0	0	0
Navicula cryptonella	0	1	1	1	2	1	1	0	2
Navicula detenta	0	0	0	0	0	0	0	0	1
Navicula orbis	0	0	0	0	0	0	0	0	0
Navicula peregrina	0	0	0	0	0	0	0	0	0
Navicula scutelloides	0	2	0	1	1	1	0	1	0
Navicula simplex	0	0	0	1	0	0	0	1	0
Nitzchizia sp. I	0	0	0	0	0	0	0	0	0
Pinnularia microstauron	0	0	0	1	0	0	0	1	0
Rhoicosphenia curvata	0	0	0	0	0	0	0	0	0
Stauroneis muriella	0	0	0	0	0	1	0	0	0
Stauroneis acuta	0	0	0	0	0	0	0	0	0
Stephanodiscus rotula	0	0	0	0	0	0	1	0	1
Suriella ovalis	0	0	0	0	0	1	0	0	0
Taballiera flocculosa	0	0	0	0	0	0	0	0	0
Taballiera ventricosa	0	0	1	0	0	0	0	0	0
Unknown V	1	0	0	1	2	2	2	2	2

	Depth (cm)							
DIATOM	**175**	**180**	**185**	**190**	**195**	**200**	**205**	**210**
Achanates ostruepii	0	0	0	0	1	2	1	1
Amphora libyca	4	0	1	0	1	0	2	1
Amphora exima	0	0	1	1	1	0	0	0
Asterionella formosa	0	1	0	4	0	2	0	1
Aulacoseira distans	0	0	0	0	0	0	0	0
Aulacoseira islandica	3	1	4	1	4	0	5	0
Aulacoseira italica	2	1	4	1	1	2	2	3
Camphylodiscus hiberncus	0	2	0	0	0	0	0	0
Cocconeis placentula	20	4	32	7	16	4	10	6
Cyclostella bodanica (var. affins)	0	2	0	2	1	3	2	1
Cyclostephanos costalimbus	2	1	3	4	2	1	0	0
Cyclostephanos dubius	24	37	12	17	10	10	8	7
Cyclotela planktonica	0	0	0	0	0	0	0	0
Cyclotella ocelatta	0	0	3	1	0	0	0	0
Cyclotella radiosa	7	4	3	2	6	9	4	9
Cymbella aspera	1	0	1	0	1	0	0	0
Cymbella cistula	0	0	0	0	0	0	0	0
Cymbella cistula (var. maculta)	0	2	0	0	0	0	0	0
Cymbella silesiacum	0	0	0	0	1	0	0	0
Diatoma ancers	0	0	0	0	0	0	0	0
Diploneis elliptica	1	1	0	1	1	1	0	2
Epithemia adnata (var. porcellus)	0	0	0	0	0	0	0	0
Epithemia argus	3	0	5	1	2	0	2	0
Eunotia elegans	2	1	0	0	0	1	1	0
Eunotia vanheurckii	0	0	0	0	0	0	0	0
Fragilaria arcus	0	0	0	0	0	0	1	0
Fragilaria brevistriata	12	13	12	14	12	9	10	10
Fragilaria capucina	2	0	2	0	3	0	6	1
Fragilaria construens	9	19	8	21	17	34	15	33
Fragilaria construens (var. exigua)	0	0	0	1	0	0	0	0
Fragilaria leptosauron	0	0	0	0	0	0	0	0
Fragilaria parasitica	0	2	1	2	0	0	0	0
Fragilaria pinnata	2	1	0	1	1	2	4	2
Fragilaria reicheltii	0	2	0	0	0	0	0	0
Fragilaria robusta	0	0	1	1	0	0	0	0
Fragilaria ulna	0	0	0	0	0	1	0	0
Fragilaria virencens	0	1	0	2	0	3	0	3
Fragilaria zellieri	0	0	0	0	0	0	0	0
Gomphonema groveii	1	1	1	1	0	0	0	0
Gomponema acuminatum	0	0	0	0	0	0	0	0
Gyrosigma accuminatum	2	1	0	2	7	4	5	2
Navicula atomus	1	2	1	3	1	1	1	2
Navicula capitata	0	0	0	0	0	0	0	0
Navicula cincta	1	1	1	2	1	2	1	3
Navicula cocconeisformis	0	0	0	0	0	0	0	0
Navicula cryptonella	0	1	0	3	2	2	3	3
Navicula detenta	0	1	0	0	0	1	0	0
Navicula orbis	0	0	0	0	0	0	0	0
Navicula peregrina	0	0	0	0	0	0	0	0
Navicula scutelloides	0	0	0	1	2	4	12	2
Navicula simplex	0	0	2	2	0	0	0	2
Nitzchizia sp. I	0	0	0	0	0	0	1	0
Pinnularia microstauron	0	0	0	0	0	0	1	0
Rhoicosphenia curvata	0	0	0	0	0	0	0	0
Stauroneis muriella	0	0	0	0	0	0	1	0
Stauroneis acuta	0	0	0	0	0	0	0	0
Stephanodiscus rotula	0	1	0	2	1	2	3	2
Suriella ovalis	1	0	1	0	2	0	1	0
Taballiera flocculosa	0	0	0	0	0	0	0	1
Taballiera ventricosa	0	0	0	0	0	0	0	0
Unknown V	0	0	0	0	2	0	0	0

	Depth (cm)							
DIATOM	**215**	**220**	**225**	**230**	**235**	**240**	**247**	**250**
Achanates ostruepii	1	1	2	0	0	0	0	0
Amphora libyca	2	1	2	0	2	0	1	0
Amphora exima	0	0	0	2	0	0	0	0
Asterionella formosa	0	1	0	0	0	0	1	1
Aulacoseira distans	0	0	0	0	0	0	0	0
Aulacoseira islandica	4	0	4	0	3	0	3	2
Aulacoseira italica	1	2	0	0	1	0	0	4
Camphylodiscus hiberncus	1	0	1	0	3	1	2	0
Cocconeis placentula	13	9	8	9	7	3	6	4
Cyclostella bodanica (var. affins)	0	1	0	0	0	3	2	1
Cyclostephanos costalimbus	0	6	0	8	1	4	5	4
Cyclostephanos dubius	7	6	7	3	9	40	15	24
Cyclotela planktonica	0	0	0	0	0	0	0	0
Cyclotella ocelatta	3	1	7	19	10	7	5	3
Cyclotella radiosa	9	8	8	2	7	16	23	7
Cymbella aspera	1	0	1	0	0	1	0	0
Cymbella cistula	0	1	0	0	0	0	1	0
Cymbella cistula (var. maculta)	0	0	0	0	0	0	0	0
Cymbella silesiacum	0	0	1	0	2	0	0	0
Diatoma ancers	0	0	0	0	0	0	0	0
Diploneis elliptica	1	1	0	0	0	0	2	0
Epithemia adnata (var. porcellus)	0	0	0	0	0	0	0	0
Epithemia argus	1	0	2	1	3	1	1	0
Eunotia elegans	1	1	1	0	0	0	1	0
Eunotia vanheurckii	0	0	0	0	0	0	0	0
Fragilaria arcus	1	0	0	0	0	0	0	0
Fragilaria brevistriata	7	11	11	11	12	4	8	6
Fragilaria capucina	2	0	2	0	2	0	2	0
Fragilaria construens	12	30	20	21	15	10	9	24
Fragilaria construens (var. exigua)	0	0	0	0	0	0	0	0
Fragilaria leptosauron	0	0	0	0	0	0	0	0
Fragilaria parasitica	0	0	0	0	0	0	0	0
Fragilaria pinnata	2	1	1	0	1	1	2	0
Fragilaria reicheltii	0	0	0	0	0	0	0	0
Fragilaria robusta	0	0	1	1	0	1	0	0
Fragilaria ulna	0	0	0	1	1	1	0	0
Fragilaria virencens	0	3	0	0	0	0	0	2
Fragilaria zellieri	0	0	0	0	0	0	0	0
Gomphonema groveii	0	0	0	1	3	0	0	1
Gomponema acuminatum	0	0	0	0	0	0	0	0
Gyrosigma accuminatum	8	2	5	0	3	1	2	1
Navicula atomus	2	1	0	7	1	1	2	2
Navicula capitata	0	0	0	0	1	0	0	0
Navicula cincta	4	3	1	9	4	2	2	7
Navicula cocconeisformis	0	2	0	0	0	0	0	0
Navicula cryptonella	1	1	2	3	1	0	0	1
Navicula detenta	1	1	0	0	0	0	0	0
Navicula orbis	0	0	0	0	0	0	0	0
Navicula peregrina	0	0	0	0	0	0	0	0
Navicula scutelloides	6	3	2	1	1	0	1	0
Navicula simplex	0	2	1	2	0	0	0	0
Nitzchizia sp. I	0	0	0	0	2	0	0	0
Pinnularia microstauron	0	0	0	0	0	0	0	0
Rhoicosphenia curvata	0	0	0	0	0	0	0	0
Stauroneis muriella	0	0	0	0	0	0	1	1
Stauroneis acuta	0	0	0	0	0	0	0	0
Stephanodiscus rotula	3	1	1	0	1	2	2	4
Suriella ovalis	4	0	5	0	0	0	0	0
Taballiera flocculosa	0	0	0	0	0	0	0	0
Taballiera ventricosa	0	0	0	0	0	0	0	0
Unknown V	1	1	0	0	1	0	0	0

	Depth (cm)							
DIATOM	**255**	**260**	**265**	**270**	**275**	**280**	**284**	**290**
Achanates ostruepii	1	1	2	2	0	0	0	0
Amphora libyca	3	0	0	0	1	0	0	0
Amphora exima	0	0	1	0	2	0	0	0
Asterionella formosa	0	0	1	0	3	0	0	1
Aulacoseira distans	0	0	0	0	0	0	0	0
Aulacoseira islandica	3	4	4	4	10	2	5	8
Aulacoseira italica	5	7	4	6	2	3	3	8
Camphylodiscus hiberncus	1	0	0	0	0	0	0	0
Cocconeis placentula	6	3	6	4	3	4	8	3
Cyclostella bodanica (var. affins)	2	5	6	6	6	3	8	3
Cyclostephanos costalimbus	5	1	4	0	2	2	0	1
Cyclostephanos dubius	16	15	17	20	23	20	29	22
Cyclotela planktonica	0	0	0	0	0	0	0	0
Cyclotella ocelatta	2	0	0	0	0	0	1	0
Cyclotella radiosa	10	7	9	8	12	5	7	7
Cymbella aspera	1	0	0	0	0	0	0	0
Cymbella cistula	0	0	1	0	0	0	0	0
Cymbella cistula (var. maculta)	0	0	0	0	0	0	0	0
Cymbella silesiacum	0	0	0	0	0	0	0	0
Diatoma ancers	0	0	0	0	0	0	0	0
Diploneis elliptica	0	0	0	0	0	0	0	0
Epithemia adnata (var. porcellus)	0	0	0	0	0	0	0	0
Epithemia argus	2	0	1	0	0	0	1	2
Eunotia elegans	1	0	1	0	0	0	1	0
Eunotia vanheurckii	0	0	1	1	1	0	0	0
Fragilaria arcus	0	0	0	0	0	0	0	0
Fragilaria brevistriata	9	10	8	7	8	8	6	6
Fragilaria capucina	0	1	1	3	2	1	2	0
Fragilaria construens	16	27	15	19	10	37	13	25
Fragilaria construens (var. exigua)	0	0	0	0	0	0	0	0
Fragilaria leptosauron	0	0	0	0	0	0	0	0
Fragilaria parasitica	0	0	1	0	0	1	0	0
Fragilaria pinnata	0	1	0	1	0	0	0	0
Fragilaria reicheltii	0	0	0	0	0	0	0	0
Fragilaria robusta	1	0	0	1	0	1	1	0
Fragilaria ulna	0	0	0	0	1	0	0	0
Fragilaria virencens	0	0	0	0	0	0	0	0
Fragilaria zellieri	0	0	0	0	0	0	0	1
Gomphonema groveii	0	0	2	0	0	0	0	0
Gomponema acuminatum	0	0	0	0	0	0	0	0
Gyrosigma accuminatum	3	4	2	1	2	2	2	1
Navicula atomus	2	2	2	0	2	2	1	1
Navicula capitata	0	0	0	0	1	0	0	0
Navicula cincta	3	2	4	2	0	1	3	2
Navicula cocconeisformis	0	0	0	0	0	0	0	0
Navicula cryptonella	1	3	1	2	2	2	2	1
Navicula detenta	1	1	1	0	1	0	0	0
Navicula orbis	0	0	0	2	0	0	0	0
Navicula peregrina	0	0	0	0	0	0	0	0
Navicula scutelloides	0	0	0	0	0	0	0	0
Navicula simplex	1	3	0	1	0	1	0	1
Nitzchizia sp. I	0	0	0	0	0	0	0	0
Pinnularia microstauron	0	0	0	0	0	0	0	0
Rhoicosphenia curvata	0	0	0	0	0	0	0	0
Stauroneis muriella	1	0	0	0	0	1	0	0
Stauroneis acuta	0	0	0	0	0	0	0	0
Stephanodiscus rotula	4	6	6	5	6	5	6	6
Suriella ovalis	0	0	0	0	0	0	0	0
Taballiera flocculosa	0	0	0	0	0	0	0	0
Taballiera ventricosa	0	0	0	0	0	0	0	0
Unknown V	0	0	1	0	0	0	0	0

	Depth (cm)							
DIATOM	**295**	**300**	**305**	**310**	**315**	**320**	**325**	**330**
Achanates ostruepii	0	0	1	0	0	0	0	0
Amphora libyca	1	0	0	0	1	0	0	1
Amphora exima	0	0	1	0	0	0	0	0
Asterionella formosa	0	0	1	1	0	1	1	1
Aulacoseira distans	0	0	0	0	0	0	0	0
Aulacoseira islandica	8	3	7	2	2	4	9	3
Aulacoseira italica	6	2	5	1	2	5	5	1
Camphylodiscus hiberncus	0	0	0	0	0	0	0	0
Cocconeis placentula	3	4	6	3	3	3	4	4
Cyclostella bodanica (var. affins)	5	3	3	2	2	5	4	3
Cyclostephanos costalimbus	2	1	0	1	3	4	5	1
Cyclostephanos dubius	27	23	28	27	23	25	26	32
Cyclotela planktonica	0	0	0	0	0	0	0	0
Cyclotella ocelatta	0	0	1	0	0	0	1	3
Cyclotella radiosa	5	4	6	6	5	5	4	11
Cymbella aspera	0	0	0	0	0	0	0	0
Cymbella cistula	0	0	0	0	0	0	0	0
Cymbella cistula (var. maculta)	0	0	0	0	0	0	0	0
Cymbella silesiacum	0	0	0	0	0	0	0	0
Diatoma ancers	0	0	0	0	0	0	0	0
Diploneis elliptica	0	0	1	1	0	0	0	0
Epithemia adnata (var. porcellus)	0	0	0	0	0	0	0	0
Epithemia argus	2	1	2	0	2	0	0	0
Eunotia elegans	0	0	0	0	0	0	0	0
Eunotia vanheurckii	0	0	0	0	0	0	0	1
Fragilaria arcus	0	0	0	0	0	0	0	0
Fragilaria brevistriata	10	9	10	8	14	4	9	6
Fragilaria capucina	1	0	1	0	2	0	1	1
Fragilaria construens	11	29	14	29	22	22	10	20
Fragilaria construens (var. exigua)	0	0	0	0	0	0	0	0
Fragilaria leptosauron	0	1	0	1	0	0	0	1
Fragilaria parasitica	0	0	0	1	0	0	0	0
Fragilaria pinnata	0	0	0	0	0	0	0	0
Fragilaria reicheltii	0	0	0	0	0	0	0	0
Fragilaria robusta	1	1	0	0	0	1	0	0
Fragilaria ulna	0	1	0	1	0	0	0	0
Fragilaria virencens	0	1	0	0	1	1	2	0
Fragilaria zellieri	0	0	0	0	0	0	0	1
Gomphonema groveii	0	0	0	0	0	1	0	1
Gomponema acuminatum	0	0	0	0	0	0	0	0
Gyrosigma accuminatum	2	1	1	3	1	1	1	1
Navicula atomus	3	3	0	0	0	0	1	0
Navicula capitata	0	0	0	0	0	0	0	0
Navicula cincta	3	2	0	2	2	3	3	2
Navicula cocconeisformis	0	0	0	0	0	0	0	0
Navicula cryptonella	1	2	1	2	0	0	0	2
Navicula detenta	1	0	1	0	0	0	0	0
Navicula orbis	0	0	0	0	0	0	0	0
Navicula peregrina	0	0	0	0	0	0	0	0
Navicula scutelloides	0	0	0	0	0	0	0	0
Navicula simplex	0	0	0	1	0	0	0	0
Nitzchizia sp. I	0	0	0	0	0	0	0	0
Pinnularia microstauron	0	0	0	0	0	0	0	0
Rhoicosphenia curvata	0	0	0	0	0	0	0	0
Stauroneis muriella	0	0	0	0	0	0	0	0
Stauroneis acuta	0	0	0	0	0	0	0	0
Stephanodiscus rotula	10	10	11	9	15	15	15	9
Suriella ovalis	0	0	0	0	0	0	0	0
Taballiera flocculosa	0	0	0	0	0	0	0	0
Taballiera ventricosa	0	0	0	0	0	0	0	0
Unknown V	0	0	0	0	0	0	0	0

	Depth (cm)							
DIATOM	**335**	**339**	**345**	**350**	**355**	**360**	**365**	**370**
Achanates ostruepii	0	1	0	0	0	0	0	0
Amphora libyca	0	1	0	0	0	0	0	0
Amphora exima	1	0	0	0	0	0	0	0
Asterionella formosa	0	2	0	2	1	0	1	0
Aulacoseira distans	0	0	0	0	0	0	0	0
Aulacoseira islandica	3	3	2	3	7	6	4	1
Aulacoseira italica	4	9	9	6	8	0	7	0
Camphylodiscus hiberncus	0	0	0	0	0	0	0	0
Cocconeis placentula	5	6	5	4	3	5	6	6
Cyclostella bodanica (var. affins)	6	7	9	2	9	5	7	6
Cyclostephanos costalimbus	1	1	2	2	0	2	5	5
Cyclostephanos dubius	34	35	31	30	40	32	37	33
Cyclotela planktonica	0	0	0	0	0	0	0	0
Cyclotella ocelatta	0	0	0	0	1	0	0	0
Cyclotella radiosa	8	7	7	13	10	13	13	15
Cymbella aspera	0	0	0	0	0	0	0	0
Cymbella cistula	0	0	0	0	0	0	0	0
Cymbella cistula (var. maculta)	0	0	0	0	0	0	0	0
Cymbella silesiacum	0	0	0	0	0	0	0	0
Diatoma ancers	0	0	0	0	0	0	0	0
Diploneis elliptica	0	0	0	0	0	0	0	0
Epithemia adnata (var. porcellus)	0	0	0	0	0	0	0	0
Epithemia argus	0	0	0	0	0	0	1	0
Eunotia elegans	0	0	1	0	1	0	0	0
Eunotia vanheurckii	0	0	0	2	0	0	0	0
Fragilaria arcus	0	0	0	0	0	0	0	0
Fragilaria brevistriata	6	3	6	5	2	5	3	4
Fragilaria capucina	1	2	1	1	1	1	1	0
Fragilaria construens	13	7	10	17	8	16	5	11
Fragilaria construens (var. exigua)	0	0	0	0	0	0	0	0
Fragilaria leptosauron	0	0	0	0	0	0	0	0
Fragilaria parasitica	0	0	1	0	0	0	0	0
Fragilaria pinnata	0	1	0	0	0	0	0	1
Fragilaria reicheltii	0	0	0	0	0	0	0	0
Fragilaria robusta	0	0	0	0	0	0	0	0
Fragilaria ulna	0	0	0	0	1	0	0	0
Fragilaria virencens	0	0	2	0	0	2	0	0
Fragilaria zellieri	0	0	0	0	0	0	0	0
Gomphonema groveii	1	0	0	1	0	0	0	0
Gomponema acuminatum	0	0	0	0	0	0	0	0
Gyrosigma accuminatum	1	0	1	1	0	0	1	2
Navicula atomus	1	1	1	1	0	2	0	1
Navicula capitata	0	0	0	0	0	0	0	0
Navicula cincta	3	1	2	2	1	3	1	2
Navicula cocconeisformis	0	0	0	0	0	0	0	0
Navicula cryptonella	0	1	0	0	0	1	0	2
Navicula detenta	1	0	0	0	0	0	0	0
Navicula orbis	0	0	0	0	0	0	0	0
Navicula peregrina	0	0	0	0	0	0	0	1
Navicula scutelloides	0	0	0	0	0	0	0	0
Navicula simplex	0	0	0	0	1	1	0	0
Nitzchizia sp. I	0	0	0	0	0	0	0	0
Pinnularia microstauron	0	0	0	0	0	0	0	0
Rhoicosphenia curvata	0	0	0	0	0	0	0	0
Stauroneis muriella	0	0	0	1	0	1	0	0
Stauroneis acuta	0	0	0	0	0	0	0	0
Stephanodiscus rotula	13	10	11	7	5	6	8	7
Suriella ovalis	0	0	0	0	0	0	0	0
Taballiera flocculosa	0	0	0	0	0	0	0	0
Taballiera ventricosa	0	0	0	0	0	0	0	0
Unknown V	0	1	0	0	0	0	0	0

	Depth (cm)							
DIATOM	**375**	**380**	**385**	**390**	**395**	**400**	**405**	**410**
Achanates ostruepii	0	0	0	0	0	0	0	1
Amphora libyca	1	0	0	0	0	0	0	0
Amphora exima	0	1	0	1	0	1	0	0
Asterionella formosa	0	1	0	0	0	0	0	0
Aulacoseira distans	0	0	0	0	0	0	0	0
Aulacoseira islandica	4	8	3	3	5	2	1	2
Aulacoseira italica	8	10	7	6	10	4	8	5
Camphylodiscus hiberncus	0	0	0	1	1	1	0	1
Cocconeis placentula	4	8	6	11	5	11	7	9
Cyclostella bodanica (var. affins)	9	3	2	1	0	2	1	1
Cyclostephanos costalimbus	2	1	5	3	4	7	3	9
Cyclostephanos dubius	32	39	37	43	50	42	56	50
Cyclotela planktonica	0	0	0	0	0	0	0	0
Cyclotella ocelatta	0	0	0	1	0	0	0	1
Cyclotella radiosa	14	7	9	5	7	7	7	4
Cymbella aspera	0	0	0	0	0	0	0	0
Cymbella cistula	0	0	0	0	1	0	0	0
Cymbella cistula (var. maculta)	0	0	0	0	0	0	0	0
Cymbella silesiacum	0	0	0	0	0	0	0	0
Diatoma ancers	0	0	0	0	0	0	0	0
Diploneis elliptica	1	0	0	0	0	1	0	1
Epithemia adnata (var. porcellus)	0	0	0	0	0	0	0	0
Epithemia argus	1	0	1	1	1	0	0	0
Eunotia elegans	0	1	0	1	0	0	0	0
Eunotia vanheurckii	0	0	0	0	0	0	0	0
Fragilaria arcus	0	0	0	0	0	0	0	0
Fragilaria brevistriata	1	2	2	4	0	2	2	1
Fragilaria capucina	1	1	1	1	0	1	1	1
Fragilaria construens	15	6	14	11	6	10	9	7
Fragilaria construens (var. exigua)	0	0	0	0	0	0	0	0
Fragilaria leptosauron	0	0	0	0	0	0	0	0
Fragilaria parasitica	0	0	0	0	0	0	0	0
Fragilaria pinnata	1	3	0	2	0	1	0	2
Fragilaria reicheltii	0	0	0	0	0	0	0	0
Fragilaria robusta	0	0	0	0	0	0	0	0
Fragilaria ulna	0	0	1	0	0	0	0	0
Fragilaria virencens	0	0	0	0	1	0	0	0
Fragilaria zellieri	0	0	0	0	0	0	0	0
Gomphonema groveii	0	0	0	0	0	0	0	0
Gomponema acuminatum	0	0	0	0	0	1	0	0
Gyrosigma accuminatum	1	1	1	0	0	0	2	0
Navicula atomus	0	0	1	0	1	0	1	0
Navicula capitata	0	0	0	0	0	0	0	0
Navicula cincta	1	1	3	1	1	1	0	2
Navicula cocconeisformis	0	0	0	0	0	0	0	0
Navicula cryptonella	1	1	1	0	0	1	1	1
Navicula detenta	0	0	0	0	0	0	0	0
Navicula orbis	0	0	0	0	0	0	0	0
Navicula peregrina	0	0	0	0	0	0	0	0
Navicula scutelloides	0	0	0	0	0	0	0	0
Navicula simplex	0	1	0	0	0	0	1	1
Nitzchizia sp. I	0	0	0	0	0	0	0	0
Pinnularia microstauron	0	0	0	0	0	0	0	0
Rhoicosphenia curvata	0	0	0	0	0	0	0	0
Stauroneis muriella	0	0	0	0	1	0	0	0
Stauroneis acuta	0	0	0	0	0	0	0	0
Stephanodiscus rotula	4	5	1	5	3	4	0	4
Suriella ovalis	0	0	0	0	0	0	0	0
Taballiera flocculosa	0	0	0	0	0	0	0	0
Taballiera ventricosa	0	0	0	0	0	0	0	0
Unknown V	0	0	1	0	0	0	0	0

	Depth (cm)							
DIATOM	**415**	**420**	**425**	**430**	**435**	**440**	**445**	**450**
Achanates ostruepii	0	0	0	2	0	4	0	2
Amphora libyca	0	0	0	0	0	1	0	1
Amphora exima	0	0	1	1	0	1	1	1
Asterionella formosa	1	2	1	0	0	0	0	0
Aulacoseira distans	0	0	0	0	0	0	0	0
Aulacoseira islandica	3	1	2	1	3	0	0	0
Aulacoseira italica	4	6	4	5	3	1	0	2
Camphylodiscus hiberncus	1	1	1	0	1	0	0	2
Cocconeis placentula	5	8	6	6	10	8	10	7
Cyclostella bodanica (var. affins)	0	0	0	1	0	1	0	0
Cyclostephanos costalimbus	10	12	11	10	11	7	10	13
Cyclostephanos dubius	51	42	47	36	21	22	21	19
Cyclotela planktonica	0	0	0	0	0	0	0	0
Cyclotella ocelatta	0	0	0	0	1	5	2	3
Cyclotella radiosa	5	1	1	1	1	1	3	2
Cymbella aspera	0	0	0	0	0	0	0	0
Cymbella cistula	0	1	0	0	0	1	0	0
Cymbella cistula (var. maculta)	0	0	0	0	0	0	0	0
Cymbella silesiacum	0	0	0	0	0	0	0	0
Diatoma ancers	0	0	0	0	0	0	0	0
Diploneis elliptica	1	0	0	2	2	0	1	0
Epithemia adnata (var. porcellus)	0	0	0	0	0	0	0	0
Epithemia argus	1	1	2	1	2	0	1	0
Eunotia elegans	1	0	0	0	0	0	0	0
Eunotia vanheurckii	0	0	0	0	2	0	0	0
Fragilaria arcus	0	0	0	0	0	0	0	0
Fragilaria brevistriata	3	1	6	1	12	10	5	11
Fragilaria capucina	1	0	0	0	1	0	1	0
Fragilaria construens	8	14	12	21	24	23	30	24
Fragilaria construens (var. exigua)	0	0	0	0	0	0	0	0
Fragilaria leptosauron	0	0	0	0	0	0	0	0
Fragilaria parasitica	0	0	0	0	0	0	0	0
Fragilaria pinnata	0	3	0	2	3	6	1	3
Fragilaria reicheltii	0	0	0	0	0	0	0	0
Fragilaria robusta	0	0	0	0	0	0	0	0
Fragilaria ulna	0	0	0	0	0	0	0	0
Fragilaria virencens	0	0	0	0	0	0	0	0
Fragilaria zellieri	0	0	0	0	0	0	0	0
Gomphonema groveii	0	0	0	3	0	0	0	0
Gomponema acuminatum	0	0	0	0	0	0	0	0
Gyrosigma accuminatum	0	0	1	0	1	0	1	0
Navicula atomus	1	0	1	0	1	0	2	1
Navicula capitata	0	0	0	0	0	0	2	0
Navicula cincta	2	2	1	0	2	2	2	1
Navicula cocconeisformis	0	0	0	0	0	0	0	0
Navicula cryptonella	2	1	1	1	1	1	0	1
Navicula detenta	0	0	0	0	0	0	1	0
Navicula orbis	0	0	0	0	0	0	0	0
Navicula peregrina	0	0	0	0	0	0	0	0
Navicula scutelloides	0	0	0	0	0	1	0	2
Navicula simplex	0	0	0	0	0	0	0	1
Nitzchizia sp. I	0	0	0	0	0	0	0	0
Pinnularia microstauron	0	0	0	0	0	0	0	0
Rhoicosphenia curvata	0	0	0	0	0	0	0	0
Stauroneis muriella	0	0	0	1	0	1	0	2
Stauroneis acuta	0	0	0	0	0	0	0	0
Stephanodiscus rotula	2	2	0	5	0	1	1	1
Suriella ovalis	0	0	0	0	0	0	0	0
Taballiera flocculosa	0	0	0	0	0	0	0	0
Taballiera ventricosa	0	0	0	0	0	0	0	0
Unknown V	0	0	0	0	0	0	0	0

	Depth (cm)							
DIATOM	**455**	**460**	**465**	**470**	**476**	**480**	**485**	**489**
Achanates ostruepii	0	1	0	1	0	2	0	1
Amphora libyca	0	0	0	0	1	1	1	1
Amphora exima	0	1	1	1	0	1	0	1
Asterionella formosa	0	1	0	0	1	0	1	1
Aulacoseira distans	0	0	0	0	0	0	0	0
Aulacoseira islandica	2	1	0	2	4	3	5	2
Aulacoseira italica	4	3	1	3	8	0	7	3
Camphylodiscus hiberncus	1	1	0	0	0	1	1	0
Cocconeis placentula	8	9	14	10	7	5	4	3
Cyclostella bodanica (var. affins)	0	0	1	0	0	0	1	0
Cyclostephanos costalimbus	4	26	7	10	7	4	7	7
Cyclostephanos dubius	16	11	27	19	23	26	20	23
Cyclotela planktonica	0	0	0	0	0	0	0	0
Cyclotella ocelatta	5	5	0	1	1	0	0	0
Cyclotella radiosa	2	0	2	0	0	1	3	1
Cymbella aspera	0	0	0	0	0	0	0	0
Cymbella cistula	0	0	0	1	0	0	0	0
Cymbella cistula (var. maculta)	0	0	0	0	0	0	0	0
Cymbella silesiacum	0	0	0	0	0	0	0	0
Diatoma ancers	0	0	0	0	0	0	0	0
Diploneis elliptica	1	0	0	1	0	0	0	0
Epithemia adnata (var. porcellus)	0	0	0	0	0	0	0	0
Epithemia argus	1	0	0	1	0	1	0	0
Eunotia elegans	0	0	0	0	0	0	1	0
Eunotia vanheurckii	0	0	0	0	0	0	0	0
Fragilaria arcus	0	0	0	0	0	0	0	0
Fragilaria brevistriata	8	10	14	11	10	13	15	16
Fragilaria capucina	0	0	1	0	1	0	0	0
Fragilaria construens	28	19	21	29	25	34	29	30
Fragilaria construens (var. exigua)	0	0	0	0	0	0	0	0
Fragilaria leptosauron	0	0	0	0	0	0	0	0
Fragilaria parasitica	0	1	0	0	1	0	0	0
Fragilaria pinnata	1	4	2	3	1	3	0	3
Fragilaria reicheltii	0	0	0	0	0	0	0	0
Fragilaria robusta	1	0	2	1	0	0	0	0
Fragilaria ulna	0	0	0	0	0	0	0	0
Fragilaria virencens	3	0	0	0	0	0	1	0
Fragilaria zellieri	0	0	0	0	0	0	0	0
Gomphonema groveii	1	1	0	0	0	0	0	0
Gomponema acuminatum	0	0	0	0	0	0	0	0
Gyrosigma accuminatum	0	0	1	0	1	0	0	1
Navicula atomus	1	1	0	1	2	2	0	2
Navicula capitata	0	0	0	0	0	0	0	0
Navicula cincta	1	2	3	0	0	0	1	1
Navicula cocconeisformis	0	0	0	0	0	0	1	0
Navicula cryptonella	2	1	1	2	0	0	1	0
Navicula detenta	1	0	0	0	1	0	0	0
Navicula orbis	0	0	0	0	0	0	0	0
Navicula peregrina	0	0	0	0	0	0	0	0
Navicula scutelloides	0	0	0	1	3	1	0	2
Navicula simplex	0	2	0	1	0	1	1	0
Nitzchizia sp. I	0	0	0	0	0	0	0	0
Pinnularia microstauron	0	0	0	0	0	0	0	0
Rhoicosphenia curvata	0	0	0	0	0	0	0	0
Stauroneis muriella	0	0	0	0	0	1	0	1
Stauroneis acuta	0	0	0	0	0	0	0	0
Stephanodiscus rotula	0	0	0	1	0	0	0	0
Suriella ovalis	0	0	0	0	0	0	0	0
Taballiera flocculosa	0	0	0	0	0	0	0	0
Taballiera ventricosa	0	0	0	0	0	0	0	0
Unknown V	0	0	0	0	0	0	0	0

9.4 Diatoms Identified and Their Ecological Requirements

	Salinity	Life form	pH tolerance	Trophic conditions	Source
Achanates ostruepii		N.D.	6	5	1
Amphora libyca		7	1	1	2
Amphora exima	5	7	1	1	2
Asterionella formosa	9	2	5	3	2
Aulacoseira distans	9	4	7	7	2
Aulacoseira islandica	9	2	4	8	2
Aulacoseira italica	9	4	5	3	1
Camphylodiscus hiberncus	9	8	4	2	2
Cocconeis placentula	8	6	4	3	2
Cyclotella bodanica (var. affins)		N.D.	6	6	1
Cyclostephanos costalimbus		N.D.	N.D.	N.D.	N.D.
Cyclostephanos dubius	9	2	4	2	2
Cyclotella planktonica		N.D.	N.D.	N.D.	N.D.
Cyclotella ocelatta	0	4	4	6	1
Cyclotella radiosa	9	2	4	2	1
Cymbella aspera	10	6	4	2	2
Cymbella cistula	9	6	4	3	2
Cymbella cistula (var. maculta)	9	N.D.	4	2	1
Cymbella silesiacum	10	7	6	9	2
Diatoma ancers		N.D.	N.D.	N.D.	N.D.
Diploneis elliptica	11	8	4	9	2
Epithemia adnata (var. porcellus)	10	6	3	3	2
Epithemia argus		6	4	4	1
Eunotia elegans		6	8	6	1
Eunotia vanheurckii	12	6	8	7	2
Fragilaria arcus		N.D.	4	5	1
Fragilaria brevistriata	5	7	4	3	2
Fragilaria capucina	10	3	5	3	2
Fragilaria construens	10	3	4	3	2
Fragilaria construens (var. exigua)		3	4	3	1
Fragilaria leptosauron		N.D.	4	3	1
Fragilaria parasitica		N.D.	4	4	1
Fragilaria pinnata	8	7	5	2	2
Fragilaria reicheltii		N.D.	6	3	1
Fragilaria robusta		N.D.	N.D.	N.D.	N.D.
Fragilaria ulna		N.D.	4	4	1
Fragilaria virencens	8	6	5	9	2
Fragilaria zellieri		N.D.	N.D.	N.D.	N.D.
Gomphonema grovei	9	5	6	3	2
Gomponema acuminatum	9	6	5	9	2
Gyrosigma accuminatum	10	8	4	2	2
Navicula atomus	9	8	5	2	2
Navicula capitata	10	8	4	2	2
Navicula cincta	8	8	4	9	2
Navicula cocconeisformis	12	8	7	6	2
Navicula cryptonella	11	8	5	4	2
Navicula detenta		N.D.	N.D.	N.D.	N.D.
Navicula orbis		N.D.	N.D.	N.D.	N.D.
Navicula peregrina	7	N.D.	7	2	1
Navicula scutelloides	9	8	3	2	2
Navicula simplex		N.D.	N.D.	N.D.	N.D.
Nitzchizia sp. I		U.S.	U.S.	U.S.	U.S.
Pinnularia microstauron	9	8	6	0	2
Rhoicosphenia curvata		6	N.D.	N.D.	2
Stauroneis muriella	9	8	0	0	2
Stauronies acuata	9	8	4	9	2
Stephanodiscus rotula	9	2	3	2	2
Suriella ovalis	7	8	4	2	2
Taballiera flocculosa	12	3	8	7	2
Taballiera ventricosa		N.D.	N.D.	N.D.	N.D.
Unknown V		U.S.	U.S.	U.S.	U.S.

Key to Salinity Preferences

0	unknown
2	polyhalobous (oligo)euryhaline
3	polyhalobous (meio)euryhaline
4	polyhalobous (meso)euryhaline
5	polyhalobous (pleio)euryhaline
6	mesohalobous euryhaline
7	mesohalobous (holo)euryhaline
11	oligohalobous (pleio)euryhaline
10	oligohalobous (meso)euryhaline
9	oligohalobous (meio)euryhaline
8	oligohalobous (oligo)euryhaline
12	oligohalobous halophobous

Key to Life Forms

0	Unknown
2	Euplanktonic
3	Tychoplanktonic (epontic origin)
4	Tychoplanktonic (benthic origin)
5	Tychoplanktonic (benthic and epontic origin)
6	Epontic
7	Epontic and benthic
8	Benthic

Key to pH Preferences

0	unknown
1	irrelevant
2	alkalibiontic
3	alkalibiontic - alkaliphilous
4	alkaliphilous
5	alkaliphilous to cirumneutral
6	circumneutral
7	circumneutral - acidophilous
8	acidophilous
9	acidophilous - acidobiontic
10	acidobiontic
11	indifferent

Key to Trophic Preferences

0	unknown
1	irrelevant
2	eutrophic
3	eutrophic to mesotrophic
4	mesotrophic
5	mesotrophic to oligotrophic
6	oligotrophic
7	oligotrophic to dystrophic
8	eutrophic to oligotrophic
9	eutrophic to dystrophic

Notes

U.S. - Unidentfied of Unknown Species, not able to assign ecological data.
N.D. - No data available on ecological requirments.

Sources

1. van Dam *et al*. (1994)
2. Denys (1991)

9.5 Data Pertaining to Assignment of Diatoms to Ecological Groupings

Diatom pH data

Depth (cm)	alkalibiontic - alkaliphilous (% T.D.A.)	alkaliphilous (% T.D.A.)	alkaliphilous - cirumneutral (% T.D.A.)	circumneutral (% T.D.A.)	circumneutral - acidophilous (% T.D.A.)	acidophilous (% T.D.A.)	pH index
130	0	92	6	1	0	1	81
135	2	86	9	3	0	0	74
140	0	85	12	2	0	0	66
145	1	88	8	3	0	0	76
150	1	81	15	2	0	1	60
155	1	89	8	1	0	0	80
160	1	83	9	6	0	2	58
165	1	91	6	3	0	0	82
170	1	80	15	3	0	1	57
175	0	89	8	1	0	2	70
180	1	87	6	5	0	1	72
185	0	90	8	2	0	0	78
190	3	77	16	3	0	1	60
195	4	82	10	4	0	0	74
200	6	76	12	5	0	1	64
205	16	64	16	4	0	1	84
210	4	75	16	3	0	2	57
215	9	79	9	2	0	1	90
220	5	79	10	3	2	1	69
225	4	85	7	4	0	1	76
230	1	86	12	1	0	0	74
235	2	86	6	6	0	0	71
240	3	90	2	4	0	1	85
247	3	86	8	3	0	1	75
250	4	85	10	2	0	0	83
255	4	82	10	3	0	1	76
260	6	74	14	6	0	0	68
265	6	73	9	10	0	1	54
270	6	73	12	8	0	1	55
275	7	74	11	7	0	1	64
280	5	84	9	3	0	0	84
284	7	76	9	8	0	1	65
290	6	78	12	3	0	0	77
295	10	72	12	6	0	0	77
300	10	79	8	3	0	0	94
305	11	76	9	4	0	0	92
310	10	83	4	3	0	0	101
315	15	75	7	3	0	0	107
320	16	71	7	6	0	0	98
325	16	71	10	4	0	0	100
330	9	81	5	4	0	1	90
335	13	73	7	7	0	0	93
339	11	65	16	8	0	0	65
345	11	66	13	9	0	1	63
350	8	77	10	3	0	2	75
355	5	73	11	9	0	2	51
360	6	83	6	5	0	0	83
365	8	75	9	8	0	0	73
370	7	80	5	6	1	1	80
375	4	76	11	9	0	0	57
380	5	74	16	4	0	1	60
385	1	85	11	3	0	0	70
390	5	83	9	2	0	1	82
395	3	83	14	0	0	0	76
400	5	83	9	3	0	0	81
405	0	88	11	1	0	0	73
410	4	84	10	1	0	0	84
415	2	86	10	0	0	1	75
420	3	83	14	0	0	0	76
425	0	91	8	0	0	0	81
430	6	78	10	7	0	0	73
435	0	89	9	0	0	2	70
440	2	83	9	6	0	0	70
445	1	92	6	0	0	0	87
450	3	85	9	3	0	0	78
455	1	84	14	1	0	0	69
460	0	84	14	2	0	0	67
465	0	92	6	1	0	1	82
470	2	87	10	1	0	0	79
476	4	82	14	0	0	0	79
480	1	91	5	2	0	0	86
485	0	86	11	1	1	1	65
489	2	87	10	1	0	0	78

Diatom Trophic data

Depth (cm)	Eutrophic (% T.D.A.)	Mesotrophic - eutrophic (% T.D.A.)	Mesotrophic (% T.D.A.)	Oligotrophic - mesotrophic (% T.D.A.)	Oligotrophic (% T.D.A.)	Eutrophic to dystrophic (% T.D.A.)	Trophic Index
130	28	62	0	0	2	6	436
135	27	59	2	2	1	4	427
140	22	66	2	0	3	4	420
145	29	53	2	1	2	3	429
150	20	55	4	0	3	9	429
155	34	48	5	1	0	1	433
160	26	50	5	0	7	3	407
165	34	53	1	0	1	1	437
170	35	51	3	0	2	3	435
175	40	46	3	0	2	2	438
180	50	39	3	0	2	3	446
185	23	62	6	0	0	1	420
190	32	49	5	0	2	5	431
195	33	50	4	1	2	3	429
200	31	51	3	2	5	7	424
205	38	42	4	2	2	2	429
210	27	54	4	1	2	8	433
215	43	39	2	2	1	5	450
220	28	55	1	1	4	6	426
225	31	51	4	2	1	3	427
230	21	60	5	0	0	9	436
235	28	51	4	0	0	6	437
240	67	24	2	0	3	2	460
247	53	33	1	0	3	4	455
250	43	44	1	0	1	8	457
255	42	38	3	1	3	4	441
260	35	47	3	1	5	2	422
265	39	38	3	2	7	4	421
270	38	41	2	2	6	2	420
275	48	28	3	0	6	0	430
280	36	53	3	0	3	2	430
284	45	32	4	0	8	3	423
290	38	43	3	0	3	2	433
295	47	31	3	0	5	3	439
300	42	45	4	0	3	3	435
305	46	37	3	1	3	1	440
310	46	42	4	0	2	3	442
315	46	42	3	0	2	3	444
320	50	36	1	0	5	4	444
325	52	30	0	0	4	4	455
330	52	36	2	0	3	2	448
335	57	29	1	0	6	3	445
339	56	29	1	1	7	1	436
345	53	30	1	0	10	3	431
350	53	35	0	0	2	3	456
355	55	25	1	0	11	1	425
360	54	27	1	0	5	5	451
365	63	22	2	0	7	1	443
370	65	21	3	0	6	2	450
375	53	29	2	0	9	2	430
380	56	28	1	0	4	1	448
385	55	31	3	0	3	3	452
390	58	34	1	0	2	1	454
395	67	23	1	0	0	3	475
400	63	28	1	0	2	2	460
405	69	26	1	0	2	0	464
410	68	24	1	1	1	2	471
415	68	22	4	0	1	2	467
420	62	33	1	0	0	2	466
425	61	30	3	0	0	1	462
430	54	37	1	2	1	2	452
435	39	50	3	0	0	4	446
440	39	49	1	4	1	2	433
445	41	50	1	0	0	4	448
450	42	47	2	2	0	1	441
455	28	57	4	0	0	5	435
460	43	47	2	1	0	2	445
465	39	51	1	0	1	3	443
470	36	54	3	1	0	1	435
476	38	54	1	0	0	0	440
480	37	52	1	2	0	0	435
485	32	55	1	0	3	2	428
489	38	55	0	1	0	1	439

Diatom Salinity Data

Depth (cm)	Mesohalobous euryhaline (% T.D.A.)	Oligohalobous (holo)euryhaline (% T.D.A.)	Oligohalobous (pleio)euryhaline (% T.D.A.)	Oligohalobous (meso)euryhaline (% T.D.A.)	Oligohalobous (meio)euryhaline (% T.D.A.)	oligohalobous (oligo)euryhaline (% T.D.A.)	Oligohalobous halophobous (% T.D.A.)	Salinity Index
130	8	0	2	54	25	10	0	289
135	8	0	1	52	24	14	0	280
140	11	0	2	54	22	12	0	299
145	11	0	1	46	25	16	0	291
150	8	0	4	38	32	18	0	268
155	6	1	2	33	39	19	0	250
160	12	0	1	38	38	11	0	287
165	9	0	0	29	38	24	0	252
170	9	0	3	32	44	13	0	269
175	14	1	1	16	43	25	0	265
180	14	0	2	21	56	7	0	290
185	15	2	1	13	30	39	0	256
190	18	0	5	26	37	14	0	309
195	14	2	4	31	29	20	0	298
200	10	0	4	42	32	12	0	286
205	11	1	3	28	41	16	0	273
210	11	0	6	38	29	15	1	286
215	8	5	2	26	38	21	0	265
220	13	0	2	38	27	19	2	281
225	14	6	2	36	29	13	0	314
230	18	0	4	30	22	25	0	305
235	16	0	1	30	38	15	0	297
240	5	0	0	14	73	7	0	231
247	10	0	2	16	60	12	0	258
250	6	0	1	28	50	14	0	247
255	11	0	2	25	51	12	0	271
260	11	0	3	34	46	6	0	288
265	12	0	1	22	54	12	1	268
270	9	0	2	28	52	8	1	266
275	11	0	2	17	66	3	1	271
280	8	0	2	43	41	6	0	283
284	7	0	3	20	59	12	0	246
290	6	0	1	29	58	5	0	257
295	11	0	1	15	66	7	0	264
300	9	0	2	33	48	8	0	276
305	12	0	2	17	62	7	0	274
310	8	0	2	34	50	5	0	274
315	15	0	0	26	52	6	0	295
320	5	0	0	25	63	7	0	243
325	10	0	0	13	67	10	0	252
330	7	0	2	22	61	6	1	252
335	7	0	0	16	68	9	0	244
339	3	0	1	10	76	9	0	221
345	7	0	0	13	70	10	0	235
350	5	0	0	19	67	7	2	235
355	3	0	0	11	81	5	0	219
360	5	0	2	19	63	11	0	237
365	3	0	0	8	80	8	0	218
370	5	1	3	15	67	10	0	234
375	1	0	2	19	71	7	0	223
380	3	0	1	8	76	12	0	214
385	3	0	1	18	68	10	0	223
390	5	0	0	14	66	15	0	223
395	0	0	1	6	85	8	0	200
400	3	0	1	12	69	14	0	214
405	2	0	1	12	77	8	0	214
410	1	0	1	9	73	15	0	203
415	3	0	3	10	75	8	0	225
420	1	0	1	17	67	14	0	211
425	8	0	1	16	66	9	0	250
430	2	0	3	24	61	10	0	231
435	14	0	3	30	34	17	2	284
440	15	0	1	29	35	20	0	285
445	8	0	2	41	33	17	0	268
450	16	0	1	30	38	15	0	298
455	10	0	4	35	34	17	0	275
460	17	0	2	29	30	22	0	295
465	17	0	1	25	36	21	0	289
470	14	0	3	35	33	16	0	294
476	12	0	1	31	48	8	0	282
480	15	0	0	37	38	9	0	307
485	16	0	1	32	42	7	1	307
489	19	0	0	34	39	7	0	320

% of Shattered Frustules Data

Depth (cm)	Shattered frustules (% T.D.A.)
130	39
135	39
140	42
145	42
150	32
155	50
160	25
165	45
170	37
175	45
180	30
185	39
190	45
195	53
200	37
205	59
210	33
215	45
220	29
225	43
230	11
235	29
240	19
247	36
250	30
255	45
260	26
265	41
270	36
275	51
280	30
284	50
290	31
295	39
300	29
305	48
310	41
315	44
320	32
325	39
330	39
335	52
339	54
345	37
350	39
355	50
360	39
365	46
370	57
375	59
380	67
385	65
390	66
395	65
400	66
405	60
410	58
415	42
420	36
425	29
430	39
435	25
440	52
445	26
450	33
455	18
460	22
465	21
470	24
476	21
480	30
485	15
489	30